PRACTICAL PATH TO NET-ZERO HOMES

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Mike Najafi

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PRACTICAL PATH TO A NET-ZERO HOMES

Approved by:

Prof. Godfried Augenbroe, Advisor
School of Architecture
Georgia Institute of Technology

Prof. Russell Gentry
School of Architecture
Georgia Institute of Technology

Dr. Jason Brown
School of Architecture
Georgia Institute of Technology

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To my wife Farah and my son Kian,
For their unlimited support and love

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LIST OF SYMBOLS AND ABBREVIATIONS

ADA	Airtight Drywall Approach
ACH	Air Changes per Hour
BTP	Building Technology Program
CFD	Computational Fluid Dynamics
CPUC	California Public Utilities Commission
DHW	Domestic Hot Water
DOE	Department of Energy
GHG	GreenHouse Gas
HSPF	Heating Seasonal Performance Factor
KB	Knowledge Base
NTS	Not to Scale
NZE	Net Zero Energy
QA	Quality Assurance
SEER	Seasonal Energy Efficiency Ratio
SHGC	Solar Heat Gain Coefficient
ZEB	Zero Energy Building

SUMMARY

As demand for energy is skyrocketing around the globe, environmental challenges are becoming more severe than ever before. Carbon dioxide, methane gas and other greenhouse gases are rapidly contributing to global warming and ozone depletion phenomenon.

Buildings are among major contributors of greenhouse gases. They are consuming more than 40% of total energy and three quarter of the total electricity in the United States. It is to some distance the responsibility of building design professionals to address the impacts of their practice on the environment by reducing the energy consumption and carbon emission of their projects. This thesis aims to create a practical design guideline to help architects design energy-neutral homes in North America.

The study's primary emphasis is on reducing building energy demand by implementing core principles of building physics into the design process throughout a case study project. What makes this process unique compared to other existing green design programs is its focus on architect's knowledge to implement core energy saving design strategies into design and evaluate their performance with a normative simulation tool. Selection and analysis of building systems, financial evaluation of cost effective systems and materials, uncertainty analysis of building systems, construction cost estimating and marketing analysis of the case study project, demonstrate simple strategies for designers to use in projects with higher sensitivity.

In conclusion, the idea behind this methodology is building marketable energy-neutral homes in the current market with existing materials and none-complex technologies. The success of this design method is depends on the knowledge and skills of architects in building science, architectural design, and building construction. Despite barriers and many uncertainties embedded in this process, moving toward energy-neutral

homes will have positive impacts on environment even if it could not reach the Net-Zero balance.

CHAPTER 1

INTRODUCTION

Concerns about global warming and climate change are rising among scientists and environmental activists in a very high rate in the past several years. These global issues are becoming important agendas for politicians especially in developed countries to raise awareness of the consequences of global warming to the public and set new regulations and standards to control the treats of global warming to earth and humanity.

On the other hand, demand for fossil fuel is rising with rapid economic growth of developing countries. Rapid increase in fossil fuel prices will have short and long terms devastating impacts on economies and national securities of developed countries.

In a big scale, buildings present one of the best opportunities to economically reduce energy consumption and limit GHGs [1]. Restructuring building design, construction and operation process according to designed performance bases will reduce how buildings use energy and other resources. This process will require a cost-effective and simplified system to be implemented into the current practice.

Facing severe energy challenges: climate, energy security, and affordability, the International Energy Agency estimates an additional 1 USD spent on efficiency avoids more 2 USD investments in electrical supply [2]. Without the various energy efficiency policies that have been implemented since 1973, worldwide energy consumption would be 56% percent higher today than it would have otherwise been [2].

The net-zero energy initiative offers a comprehensive solution to the current environmental challenges facing commercial and residential buildings. On-grid net zero energy homes produce renewable energy on-site at a value equal to, or greater than, the building's total annual energy consumption [2]. The "net" portion means the building may use energy from the utility grid (electricity and/or natural gas) during some times of the day (night time) but supplies renewable energy back to the grid during other times, in a balance that equals out over the course of a year [3]. A federal goal set by the US government to build marketable Net-Zero homes by 2020 is not clear to be feasible with the current methodologies and strategies in the national scale. California has released an action plan for achieving its goals of net-zero-energy buildings. In 2008, the California Public Utilities Commission (CPUC) created a strategic plan calling for, among other energy-efficiency goals, net-zero-energy commercial buildings by 2030 and net-zero-energy residential construction by 2020. The new action plan grew out of that strategic plan and lists concrete steps the state can take to achieve these goals [3].

At the current time, NZE homes need to cut 50-70% of their energy consumption of average house to become net zero with on-site energy production or with renewable power from grid. To achieve this level of performance, designer should overcome a number of challenges and rethink the idea of Net-Zero energy home.

Throughout this study, I introduce a simple methodology to design net-zero or near zero low-rise residential buildings. The methodology is drafted from a systematic re-examination of a grid-tied townhouse project located in Atlanta, Georgia presented in an academic course in Georgia Tech, which discuss various possible scenarios in design process and decision making of a zero energy house.

Problem Background

On October 2008, the federal research and development for Net-Zero Energy buildings published the comprehensive report of the subcommittee on building technology research and development. One chapter of this report outlines a systematic methodology to design and build net-zero energy buildings. In addition, the report acknowledges and analyzes the barriers and draws a roadmap to overcome these barriers. In this report, there is no fine line between residential and commercial buildings, although they have different process in design, construction, and maintenance. This research indicates that with the current affordable technologies, we can reduce building energy consumption between 30-50% but higher cuts in energy consumption needs the integration of high performance systems and technologies to bring down energy consumption to the 60-70% range. On-site energy production can supply the 30-40% of remaining energy needs. What is clear here is that offered solutions cannot be effective in a short time period even in proactive states like California and Oregon to reach the 2020 net-zero home targets.

Building a net-zero energy home with available technologies is not a practical matter today. There are a handful of net-zero homes proving practicality of constructing net-zero energy homes in different climates around the world. However, there are common barriers blocking the manifestation of this concept. These barriers can be classified in two categories; design, and economics-costs.

Design

Designing a net-zero house is a front-loaded process. An extensive collaboration is needed between members of design team, consultants and construction contractor to complete this process. Lowering building energy need to more than 50% compared to average houses is a sensitive task for everyone involved in the project. The financial load of designing a net-zero project is noticeably greater than conventional design but operational cost of such buildings will be much lower during life time of the building.

Comparing this relatively complex and costly design process with conventional home design process with far less complexity is one of the major setbacks to integrate the net-zero concept into everyday practice.

Another setback is lack of knowledge in building science and technology within the architecture community. Traditional architecture programs have no or minor training embedded in their programs to teach fundamentals of building physics and energy systems in buildings. In commercial projects, a professional energy analyst works alongside of the design team and support their design decisions but in the case of a single-family house is not feasible to have a design team in a small project.

Time is a critical essence in residential design process. At the most, design of a single-family house should take not more than a few weeks to be completed. Most sophisticated simulation tools currently available too complex and time consuming to be used in residential design process and they require extensive training for users. Analysis of building systems and components will take a lot of time from designer, and eventually reduces their willingness to support this process.

Economics - Costs

Marketability of a house is the number one factor in home building business. Studies show American families stay, on average, five years in a house compared to the rest of the world due to variety of reasons. Purchasing a house is the biggest single investment an average American family will make in their life and they may not stay in that house for a long time. This important fact makes people cautious about the price and other important factors that may affect marketability of their investment such as maintenance costs.

A net-zero house is a unique project with significantly higher initial costs compared to a traditional home, and the initial investment in design and construction of such a project will not be returned in the life time of the building due to availability of low-cost fossil fuel energy.

This is a huge barrier for the net-zero homes concept. Even though there are tax incentive programs and marketing analysis reports claiming extra initial investment will add to market value of buildings but in reality, there is no evidence of significant market value increase in these types of homes.

Purpose of Study

Any building project starts with a systematic building programming process. Depending on the building type and size, complexity of the building program differs. In net-zero projects, the building program becomes more complex with the addition of energy factor as an important element in this process.

In case of low-rise residential projects, the subject of energy-neutral adds a lot of burden on financial side of project. The energy factor add a big load on the design side of the project while the cost of energy efficient products and systems raise the price of the building to an unmarketable level. These barriers currently limit manifestation of net-zero energy homes.

The purpose of this study is to orchestrate how to plan, design, and build an energy-Neutral house from a realistic point of view by integrating effective building science, architecture design, and building construction management to achieve economical and environmental targets and turn this process from a complex experimental practice into a practical system.

In order to achieve this target, integration of front loaded design process by an experienced designer and with consultation of a local construction team will accelerate the work process. Being target focused and have an assembled team with knowledge of green homes would secure the goal of moving toward net-zero homes.

Approach

The study is conducted through an analytical approach in four major categories. First, re-examination of the net-zero residential project's results and design process, conducted in an academic course in Georgia Tech. Second, evaluation results of past research in building and environmental science conducted in different fields such as building energy, indoor and outdoor air quality, occupants comfort and environmental pollution. Third, analysis and evaluation of two successful net-zero homes, and fourth, implementation of my personal experience in the residential design and construction process, a reality check of personal knowledge with current tools and methods. In this method, architects should have an extensive knowledge of building energy analysis, building design, and construction in order to find the optimum choice in each stage of design process.

Based on analysis and reviews mentioned, a practical method is outlined to support the idea of manifesting design and construction of net-zero homes.

Scope of Work

The scope of this project is limited to past researches, a case study project, and personal experiences. The study is focused only on grid-tied energy-neutral homes and does not cover off-grid buildings or any other types of energy conscious building programs. The proposed methodology should not be considered as a definite way to achieve net-zero energy balance in every project due to embedded uncertainties in different aspects of each project.

CHAPTER 2

NET-ZERO ENERGY HOMES

Net-Zero Energy Homes Overview

A net zero-energy building (ZEB) is a residential or commercial building with greatly reduced energy needs through efficiency gains such that the balance of energy needs can be supplied with renewable technologies [4]. The net-zero energy concept is that buildings could generate enough on-site energy to balance-out or exceed their annual energy consumption. The “net” portion means the building may use energy from the utility grid (electricity/natural gas) during some times of the day but supplies renewable energy back to the grid during other times, in a balance that equals out over the course of a year [5].

A grid-tied net-zero home normally uses conventional energy sources from utility companies when on-site energy production is not enough to meet building loads. When the on-site generation is greater than the building’s loads, excess electricity is exported to the utility grid. By using the grid to account for the energy balance, excess production can offset later energy use [4]. It is almost impossible to offset building energy demand without being tied to grid with the current technologies. On the other hand, reliability of an off-grid home is not acceptable for people live in urban areas due to wide range of uncertainty in power availability and off-grid buildings cannot feed their excess energy production back onto the grid to offset other energy uses [4].

Europeans have a different interpretation for these type of buildings; A Zero Carbon Building is one that, over a year, produces sufficient carbon-free energy to offset the carbon emitted from all fossil-fuel derived energy consumed by the building [6].

The U.S. Department of Energy’s (DOE) Building Technologies Program (BTP) works in partnership with industry, state, municipal, and other federal organizations to achieve the goals of marketable net-zero energy buildings [7]. Design and construction of affordable Net-Zero homes will be the main challenge for the year 2020. In the US, the Government's Building America 21 program is focused on research and promotion of the drive towards zero energy buildings. The schematic below sets out the pathway envisaged by Building America towards a Zero Energy Home [6].

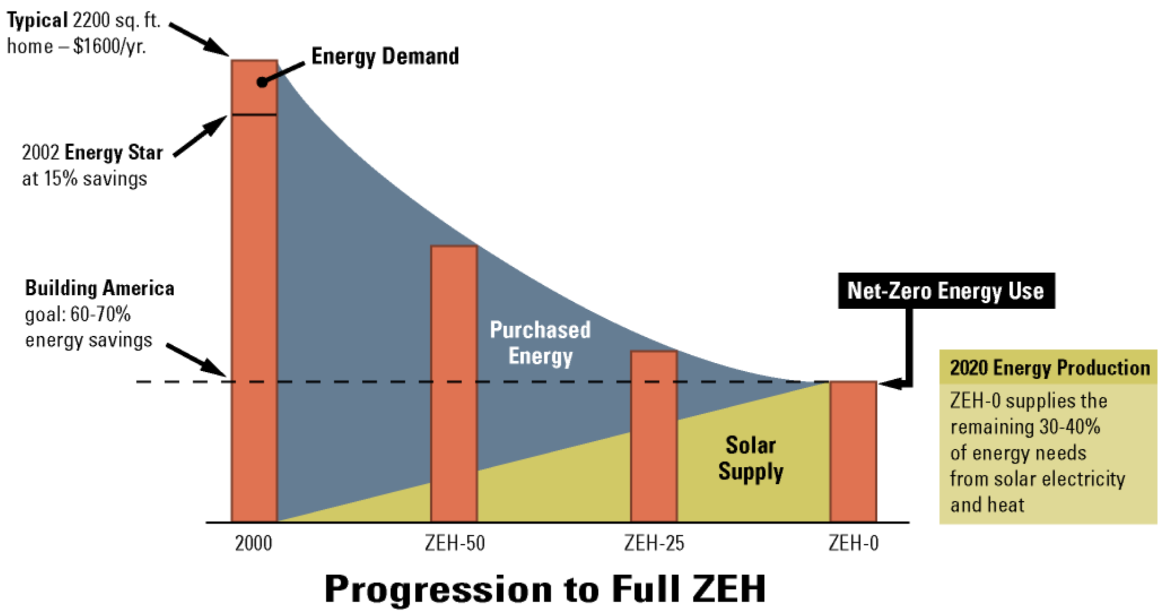


Figure 2.1: The pathway envisaged by building America towards a zero energy home [6]

History of Net-Zero Homes

The term of net-zero energy homes is relatively new but the general movement toward low-emission/energy homes started with solar passive house movements in the mid 20th century. There were approximately thirteen solar heated building completed before 1960 in the United States [8]. Those projects were the first generations of low-energy demand homes in the modern era. MIT Solar House 1 is the first project built in 1939. This two-room laboratory building was used to support developing methods to calculate the performance of the very first blackened copper solar collectors. The early solar houses of this era were mostly houses with large picture windows facing south. By the mid 1970s the number of solar houses increased and a common goal in design process of these projects was experimenting and improving soft solar energy with low technology approaches. The general ideology of that time was that the simple technology would be efficient, reliable, and less disruptive to the environment [8]. Odeillo Residences (1974), Tyrrel House, The Hofman House, and Baer House (1972) are good examples of that period in the US. The combination of concrete wall with attached greenhouse in Hofman House and the water walls of Baer House are good examples of the 1970s approach to build solar houses and energy harvesting from renewable sources. The major setback with the simple technology was lack of proper control in heat distribution and management.

One of the earliest unsuccessful versions of a net-zero energy home is The "Nulli" in Dörpe near Hannover in Germany. The “zero-energy house” by Erhard Wiers-Keiser and the organization for “Ecological Future Workshop for Minimum-energy and Zero-energy Houses was built in 1989. The project was calculated as having smaller demand values than a Passive House, but unfortunately, the consumption values during operation were higher, due to reduced air tightness, the insularity shutters on the inside, and the solar storage technology [9].

In the past decade while many experimental and practical energy-neutral homes have been built across the US and around the world, obstacles blocking the integration of the concept into mainstream building construction remain.

Overview of Two Net-Zero Homes in the United States

The Fraser House

The Fraser House is a net-zero energy house in Fraser, Colorado, which is designed with sophisticated active and passive building technologies. The house is grid-tied with all-electric systems. There is no system using fossil fuels, minimizing building air pollution solar PVs and evacuated tube solar thermal systems generate enough power to balance-out building's annual energy consumption. The house is not the only thing powered by the sun; a 17 kW on-site generator also powers two all-electric plug-in vehicles.

One important design strategy used in this home is reducing heat exchange through building envelope by increasing insulation. The house has a thickly insulated envelope with 7″ closed-cell polyurethane and 4″ exterior rigid XPS foam walls (R60), 12″ of closed-cell polyurethane and a 2 1/2″ Insul-Span half SIP roof (R85.5), and an ICF foundation with GreenBlock and 4″ exterior rigid XPS foam (R24). Other systems used in this building are; High Performance Fiberglass Widows, and automated window shading/coverings.

What makes the house unique compared to other net-zero homes is the designer's emphasis on reducing building energy demand as a key factor to achieve zero energy status. Figure 2.2 shows a perspective of the Fraser House.

Figure 2.2: Exterior view of the Fraser house in Colorado

The Yannell House

Michael Yannell is a pharmacist at Rush University Medical Center and the owner of the net zero home and a supporter of green building. He commissioned the house because he wanted to show that homes could have a much smaller environmental impact and still be beautiful. The 2,675 square foot home designed by Farr Associates, is working as a show case for others pursuing net-zero energy homes. Figure 2.3 shows some perspectives of the building.

Figure 2.3: Two views from Yannell house in Chicago

The four bedroom, solar passive home is split into two south-facing wings connected by a foyer. The northern wing contains the bedrooms, office and music room, while the south wing, which is about 10 feet shorter than the north wing, contains the kitchen, dining room and living room. Large, triple paned windows on the south sides let natural light flood into rooms, and since the south wing is shorter, light can easily access the north wing across the short courtyard [10]. This is a good example of space zoning in a solar passive home. There are also four evacuated tube collectors for a solar thermal hot water system on top of the roof. Besides the photovoltaic and solar thermal systems, a geothermal heat pump maintains the home heating and cooling. There are four wells dug 250 feet deep into the property in order to use the constant temperature of the earth to reduce energy use for heating and cooling.

The house has an elegant design and it is designed to generate 40% more electricity than it will consume during a course of a year. However, the price tag of 1.6 million dollars creates a shadow over marketability of the house.

Net-Zero Energy Homes Design Process

The design process of a net-zero building should be in line with general goals and achievements of green building initiatives. Theoretically, a building can be considered net-zero energy if it purchases all of its annual energy consumption from a renewable power facility. This is called Net-Zero Source Energy**.** Following this ideology would not solve the issues of rising energy demand across the globe and protecting environment and natural resources. Some researchers believe the greenest energy is that which is not used [11]. It is much easier to save energy compare to producing and distributing energy in large scale.

The design process of a net-zero home can be categorized in three major principles: building energy need optimization, building annual energy consumption reduction and on-site energy production.

Building energy need reduction is the most important step throughout the design process. This is a comprehensive analysis and optimization process to reduce building energy need in steady-state condition. Reducing building energy demand by analytical analysis between performances, costs, and design will direct the project into a practical path toward energy reduction. Step one is performance analysis of building orientation and geometry in reducing energy demand as well as the thermal performance of building components and assemblies such as windows and shades, roof and wall assemblies to select the optimum design scenario. From an architectural perspective, the building design (form) and siting are necessary considerations for net-zero energy, high performance green buildings. The overall form of the structure, the climate considerations, and its location and orientation to the sun in relation to the immediate environs will all affect the efficiency and effectiveness of the building [11]. Optimization of building energy demand represents optimum architectural design energy performance of the building. This study shows building energy demand can be reduced with proper design and affordable materials and technologies by 30% annually.

After reducing energy need, optimization of energy consumption is a less complex process. Building mechanical and electrical systems can be selected and sized based on optimized building energy need. Sensitive factors in this process are energy efficiency, costs, and size of systems. System selection depends on location, climate zone and availability of systems in the project's region. Scenario analysis indicates how much savings can be achieved based on efficiency and system types and the results of these analyses will led to selection of optimum building systems. Results of this study shows current affordable systems can reduce building energy consumption up to 40% annually.

The majority of net-zero buildings are grid-tied consumers of utility energy largely because the current generation of energy storage technologies is limited. In some cases, renewable energy supply can be directly purchased from power companies. In case of limitation or unavailability of green power, on-site renewable energy production should offset building's annual energy production. In this study, the selection and sizing of optimum on-site energy production systems is reviewed. One of the benefits of on-site energy generation is reversing buildings strain on utility infrastructure, especially during peak-time periods. In this phase of project, designer should analyze different possibilities of generating energy on-site based on a home's estimated annual energy consumption and other important factors. The study's approach recommends usage of the simplest, widely available technologies to minimize initial costs of systems and maintenance cost of systems during its service time.

The Case Study Project

This study is inspired by an academic course in Georgia Tech to design a net-zero energy quadplex townhome project in the City of Atlanta. Throughout re-examination and analysis of simulation results and design process of this project, which is called the case study project, a systematic methodology is formed, demonstrating design stages of a low-rise net-zero energy residential home (townhouse). Some of the important factors of this methodology are economic, marketability of the project, and availability of technologies used. The success of design in this method is heavily depends on building science, architectural design, construction knowledge, and skills of the architect. The methodology pursues the idea of transforming simplified net-zero energy design into conventional home design practice. Simplicity, affordability, and time-effectiveness are main characteristics of this methodology. In the design process of the case study project, It is clearly defined how a trained architect can design a net-zero home by using simple laws of passive design strategies and minimized energy loads and analyzing his/hers design strategies with a simplified but affective simulation tool to achieve net-zero status.

The case study project is a townhouse building with four units. These units have attached car garages and will have two or three bedroom designs, with less than 2000 square feet for each. In this type of small-scale residential project, limited budget is always an obstacle for designers as well as owners. These types of projects cannot afford a team of designers and consultants unless the number of buildings exceeds a threshold. The ideal scenario could be when a trained experienced architect/designer is able to design such projects with consideration of limited budget and time.

Systematic design Process

Successful design processes, need a step-by-step general strategie to achieve net-zero status, however some of these steps can be re-evaluated many times during the course of design, or they can be applied with combination of other steps. Re-examination of the case study project verified results of simulations and created some design indictors to support efficient design process. For instance, artificial tree planting analysis is not a necessary analysis for a residential project in many cases but general results can support designers to make better design decisions.

The design process emphasis in this study is mainly focused on energy side of architectural and construction practice and discussions are limited to subjects that would matter to reduce home's carbon footprint and energy consumption.

Site Analysis

This phase of design is a comprehensive study of the existing condition, surrounding environment, climate analysis, building orientation assessments, solar radiation assessment, and landscaping design and strategies to support building loads reduction. Results of these assessments draw some solid guidelines to design building's site plan.

Building Design Process

This chapter is an overview of general concepts and implementation strategies of building programming, space zoning and design, passive solar energy, natural lighting, and low-tech cross ventilation in design of net-zero energy homes and their effectiveness in reducing building energy demand.

Building Energy Demand Analysis

An analytical optimization process of building architectural design, orientation, and building envelope and its components is outlined in this chapter. Optimization process in this study is not only depends on performance of the design or system but also depends on other factors such as cost, to support the original idea of the marketability of project.

Building Systems

In this chapter, the selection and sizing of building mechanical and electrical systems is reviewed. Selection of an optimum system based on trade-offs between cost, durability, and maintenance is analyzed in the case study project to define a method for system selection of net-zero homes.

Building Energy Consumption Analysis

Analysis of building energy consumption depends on selection of system's types, size and efficiency and operation schedules. In this chapter, the focus is on reducing building energy consumption with a focus primarily on building systems. Economic factors and potential on-site energy production are the main factors in energy consumption analysis.

Economics, Construction and Risk Analysis and Marketing

There are many reasons in our current time blocking manifestation of net-zero energy homes. The cost of design and construction of this type of house is the biggest obstacle in this process.

Construction of net-zero buildings requires higher precision in finish details and installation of building systems. Construction methods and details recommended for the case study project are given alongside the primary goals of durability, simplicity, and cost-effectiveness.

General analysis of these driving factors during the early stages of the design process will led to a reliable and logical design system and can be categorized as part of feasibility study phase.

Pre-requirements to Design Net-Zero Homes

This study suggests a heavily front-loaded design and energy analysis process in order to achieve net-zero energy status. In comparison with a more convectional residential design process, this would involve more people and time and would increase significantly the cost and time of design. An effective and user-friendly simulation tool can support architects to analyze energy performance of the project. What is required is broad knowledge of building science and construction to enable the designer to perform energy analysis in parallel with architectural design to reduce design time process and cost. Residential buildings have a very limited budget for design and construction compared with commercial buildings. Architects who want to be involved in designing NZE homes must have proper training in energy performance analysis and simulation process. This strategy eventually will implement energy analysis into design practice.

CHAPTER 3

SITE ANALYSIS

Site analysis is one of the earliest phases of the building design process. In the case of designing net-zero houses, in addition to all of the traditional analysis that designers apply in conventional home's design there are additional actions needed to support an energy sensitive design process. Site analysis and results of the case study project is analyzed throughout this chapter as a reference to demonstrate the stages of design and analysis of a net-zero project.

Site Survey

A tree plan survey identifies the size, location, and families of trees in a property's boundary. In addition, we need to have the approximate heights and diameters of trees to enable designers to study their shading effects on the site and proposed building. This data needs to be added to site survey documents. In addition, preparation of an urban scale site plan is recommended to identify surrounding building locations, and dimensions to support analysis of their shading effects on the building with respect to building energy consumption (interior effects) and daylighting availability.

In our experimental townhouse project, a complete survey was obtained from public records. The next step is to create a tree plan survey and an urban site plan. It is important to know the local laws and codes about tree conservation and other ordinances in the project. Existing trees within a 10 foot perimeter of building setback lines are often subject to removal and replacement unless the law protects them. Existing trees within the 10' distance from the building are unlikely to survive in most cases; even carefully protected trees may die a few years after construction.

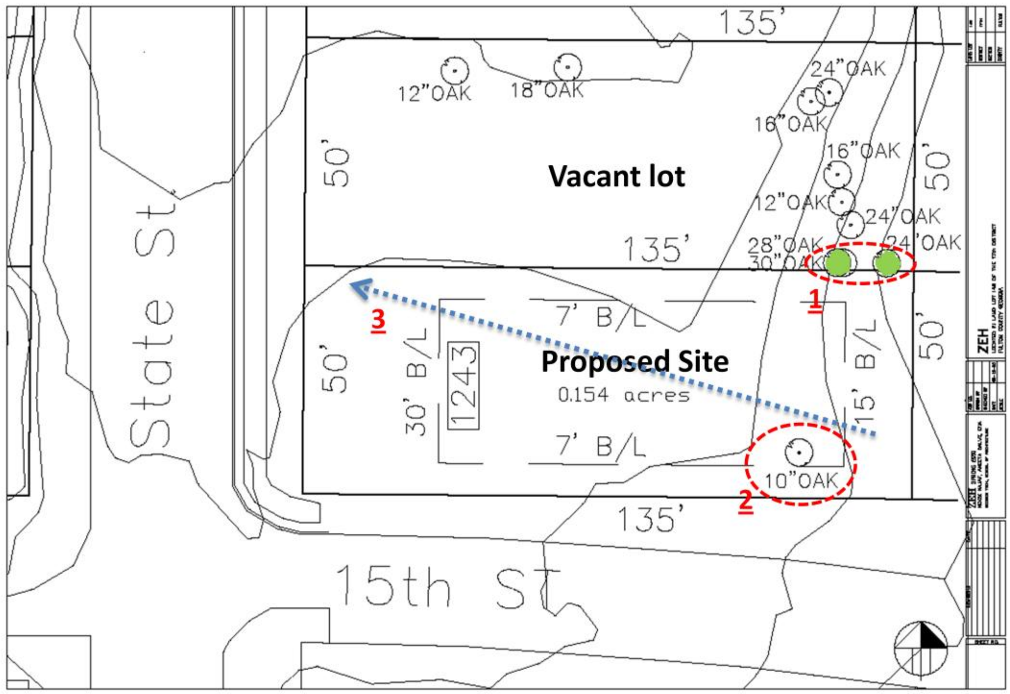


Figure 3.1: The case study townhouse project site plan (NTS)

Designers should make some key design decisions from the survey plans to support their future design. For example, which trees are going to stay, and the site design strategy concerning slope. Below are some examples:

1. Three existing large oaks (approximately 40' tall) have a great chance of surviving and have shading effects during spring and summer.
2. The existing tree will be removed due to its location.
3. The lot is relatively flat. The height difference between the highest and the lowest point is 4 feet.
4. There is no building within the 50 foot distance of our setback lines boundaries. Projects in urban areas need to have an urban survey to analyze shading and wind effects from the surroundings on the site and building.

Wind and Shading

Energy modeling tools are now widely available and can be used to support site plan wind and shading affects analysis. Wind effects analysis is not recommended for low-rise residential buildings for multiple reasons unless project is located in an area with severe wind pressure categories.

- Low-pressure winds have a minimal effect on heating load (heat exchange with the building) that can be ignored.
- The cost of CFD study with the current technology for residential buildings is significant and not feasible.

Knowing seasonal wind patterns of a project may not be affective on heating load but it can help in supporting the design of operable windows in favor of natural ventilation. In the proposed case study project, we have used Ecotect tool to study wind patterns during swing seasons in the building site. The metro Atlanta climate has a hot and humid summer and cold winter. The duration of spring and fall is very short- between 10-20 days- and humidity and pollen are major issues that significantly limit the potential of natural ventilation during the cooling season. Despite this, natural ventilation during swing seasons can help to reduce total building annual energy consumption by a small fraction, which is important to support net-zero energy goals. This strategy will not effect the building cost since operable windows are part of conventional residential building practice. Figures 3.2 and 3.3 present wind patterns for spring and winter. A simple analysis of the patterns indicates that the site receives more wind from the West during winter and spring. Since wind is not a main design factor in this location, we need to use main ideas of passive house to create a site design strategy.

- Elimination of west and east openings as much as possible to reduce unwanted solar radiation
- Optimization of south facing glazing to conserve and use free solar energy

Keeping these simple strategies in place, since there will be no or limited

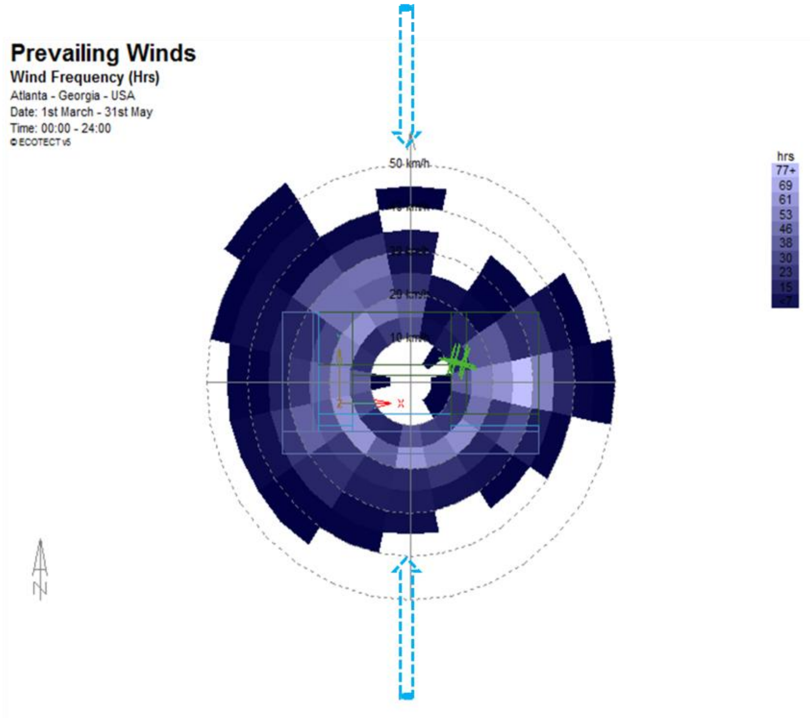


Figure 3.2: Spring wind pattern diagram (Ecotect, 2011)

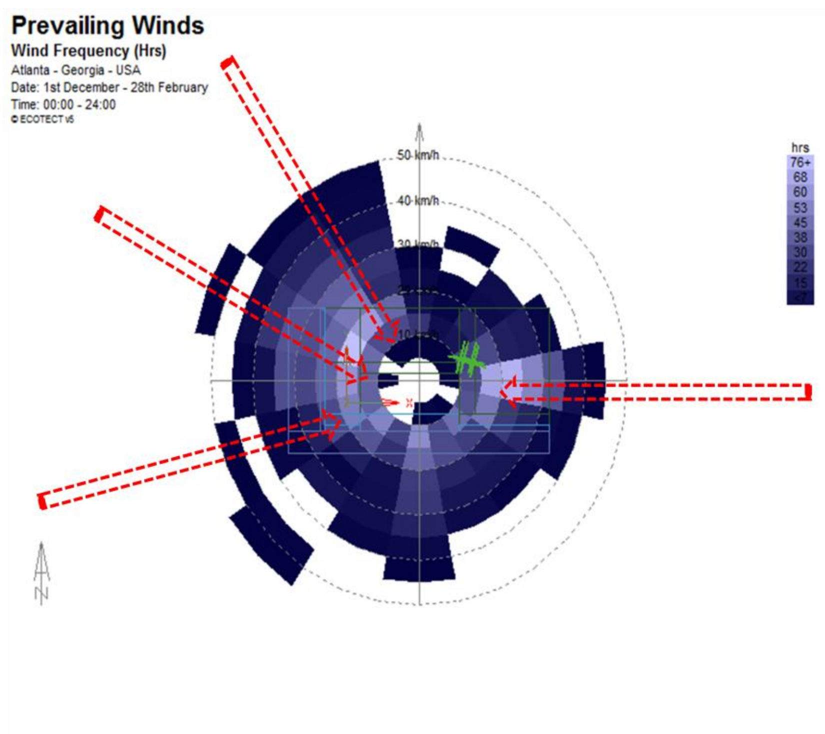


Figure 3.3: Winter wind pattern diagram (Ecotect, 2011)

numbers of windows in west and east sides of building, we can come to some simple and multi purpose strategies to support net-zero goal.

- Reducing winter wind pressure on the west and east side by planting evergreen trees (use the most adabtive tree with the environment).
- Leaving open space in south and north face of building allowing natural ventilation duing spring and fall.

These simple design strategies are acceptable since they are supporting other goals in building design. Our site plan is siding a main raod with some level of noise pollution. Evergreen trees on the west side of property can act as a sound barrier as well as provide visual privecy for backyards. They also can reduce ambient air temperature, improving termal comfort in backyards during summer.

Shading analysis is an important assessment toward reduction of building energy need. In dense urban areas, adjacent buildings can have a significant effect on reducing solar radiation. This reduction is sometimes beneficial and in some cases can reduce free winter solar gain from the south face. Before starting the schematic design phase, it is important to study these factors. Shading from adjacent buildings during the cooling season can improve thermal comfort and reduce cooling loads but also can eliminate free solar heat gain during heating seasons. Ecotect has a unique capability to provide solar radiation distribution and shading pattern on each building façade at any given day. The best method to approach is to create a 3D model of the building site with surrounding buildings and place a cubical building with approximate dimensions as proposed project. This process can be done within a few hours. With this model, designers can easily study the solar movement around the building during a year and study the shading effect of adjacent buildings on their projects.

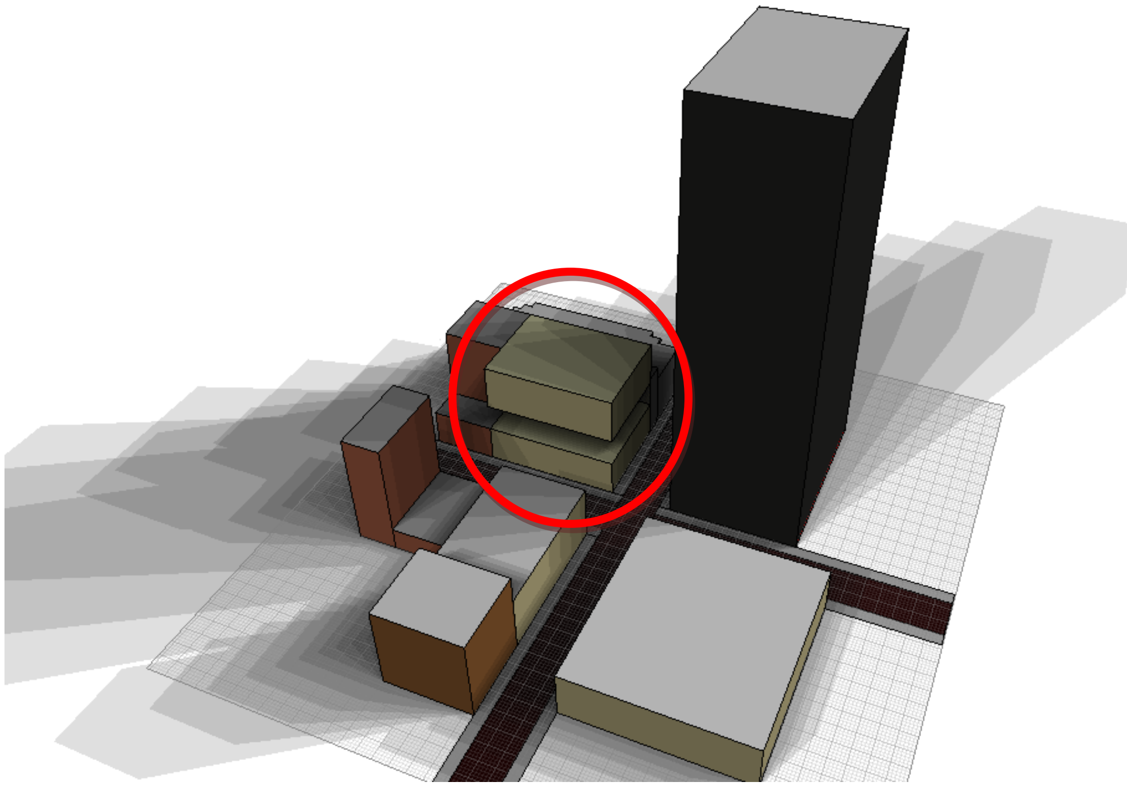


Figure 3.4: Shading pattern of a city block during 21st of June

Another practical output of this model is the steriographic diagram. This graph demonstrates the shading percentage of a selected façade for one year. Figure 3.5 shows the shading percentage of a case study building's roof. If you are looking to install solar PV panels on this roof you have to consider that during half a year and most of the morning time your roof surface will be shaded.

The shading percentage report can also be shown as a table. Figure 3.6 represents the monthly average percentage of shading for a day on each building façade. Analysis of this table can help a designer understand what to expect from solar radiation on each building façade in corelationship with srrounding buildings.

In the case study project, the building site is located in a low-density urban area. Surrounding buildings are far with no shading effeacts on proposed structure. There are a few deciduous trees on north-east side of the site that shall be protected and due to their size (40’tall, 25’ wide) may have an impact on received solar radiation. Figures 3.7 & 3.8 analyze them.

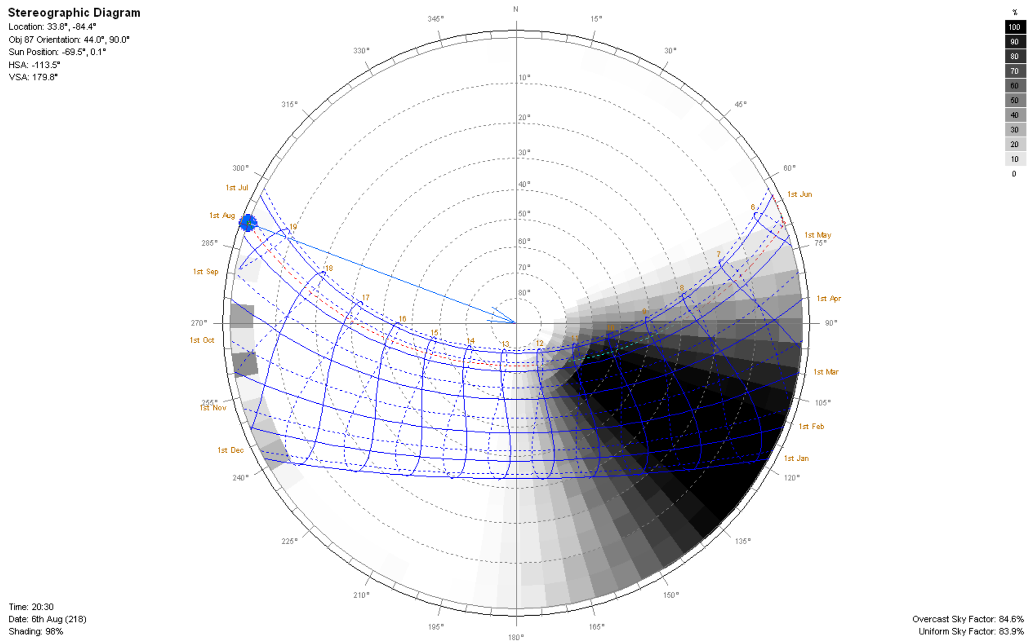
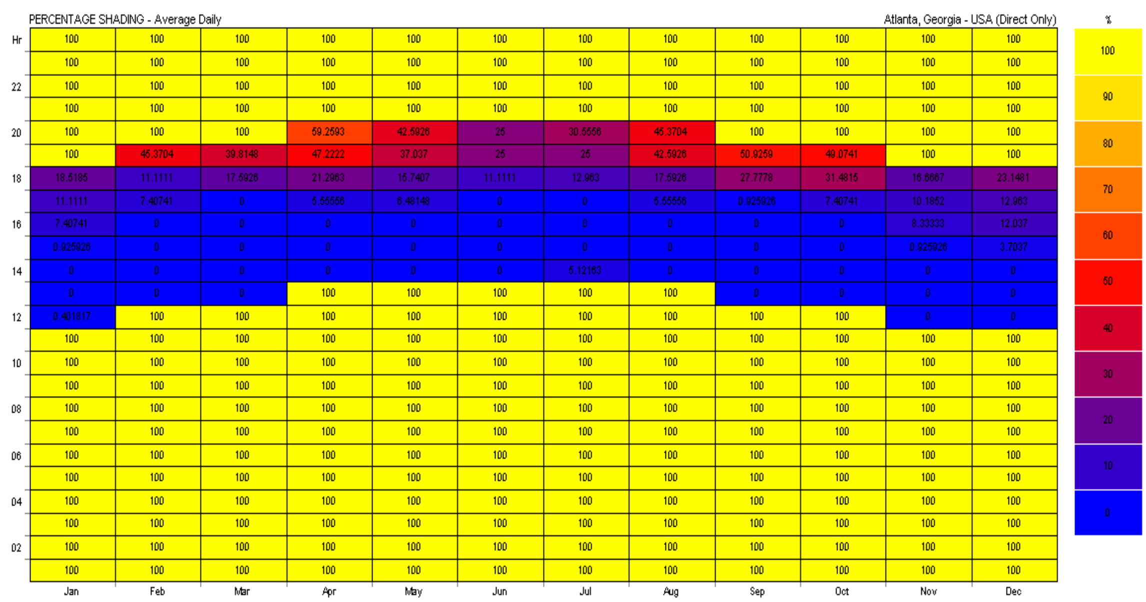


Figure 3.5: Stereographic diagram of a the case study project



PERCENTAGE SHADING - Average Daily — Atlanta, Georgia - USA (Direct Only)

Hr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hr	100	100	100	100	100	100	100	100	100	100	100	100
	100	100	100	100	100	100	100	100	100	100	100	100
22	100	100	100	100	100	100	100	100	100	100	100	100
	100	100	100	100	100	100	100	100	100	100	100	100
20	100	100	100	59.2593	42.5926	25	30.5556	45.3704	100	100	100	100
	100	45.3704	39.8148	47.2222	37.037	25	25	42.5926	50.9259	49.0741	100	100
18	18.5185	11.1111	17.5926	21.2963	15.7407	11.1111	12.963	17.5926	27.7778	31.4815	16.6667	23.1481
	11.1111	7.40741	0	5.55556	6.48148	0	0	5.55556	0.925926	7.40741	10.1852	12.963
16	7.40741	0	0	0	0	0	0	0	0	0	8.33333	12.037
	0.925926	0	0	0	0	0	0	0	0	0	0.925926	3.7037
14	0	0	0	0	0	0	5.12163	0	0	0	0	0
	0	0	0	100	100	100	100	100	0	0	0	0
12	0.401817	100	100	100	100	100	100	100	100	100	0	0
	100	100	100	100	100	100	100	100	100	100	100	100
10	100	100	100	100	100	100	100	100	100	100	100	100
	100	100	100	100	100	100	100	100	100	100	100	100
08	100	100	100	100	100	100	100	100	100	100	100	100
	100	100	100	100	100	100	100	100	100	100	100	100
06	100	100	100	100	100	100	100	100	100	100	100	100
	100	100	100	100	100	100	100	100	100	100	100	100
04	100	100	100	100	100	100	100	100	100	100	100	100
	100	100	100	100	100	100	100	100	100	100	100	100
02	100	100	100	100	100	100	100	100	100	100	100	100
	100	100	100	100	100	100	100	100	100	100	100	100

Figure 3.6: Percentage shading- average daily of a the case study project in a dense urban environment

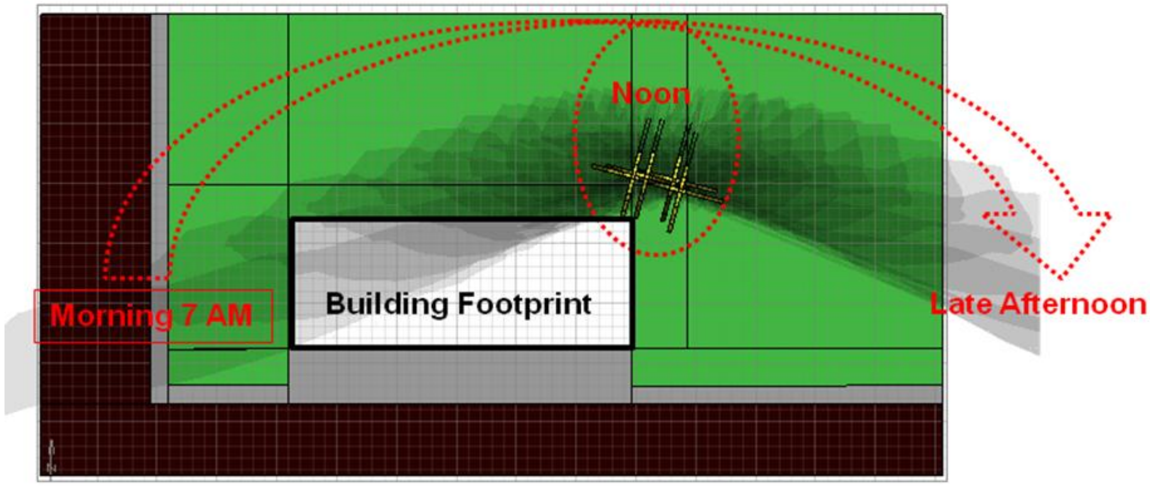


Figure 3.7: Daily shading pattern of existing trees in July 21st

The above simulation result shows some shading during morning but don't provide shades for afternoon to help lowering backyard temperature.

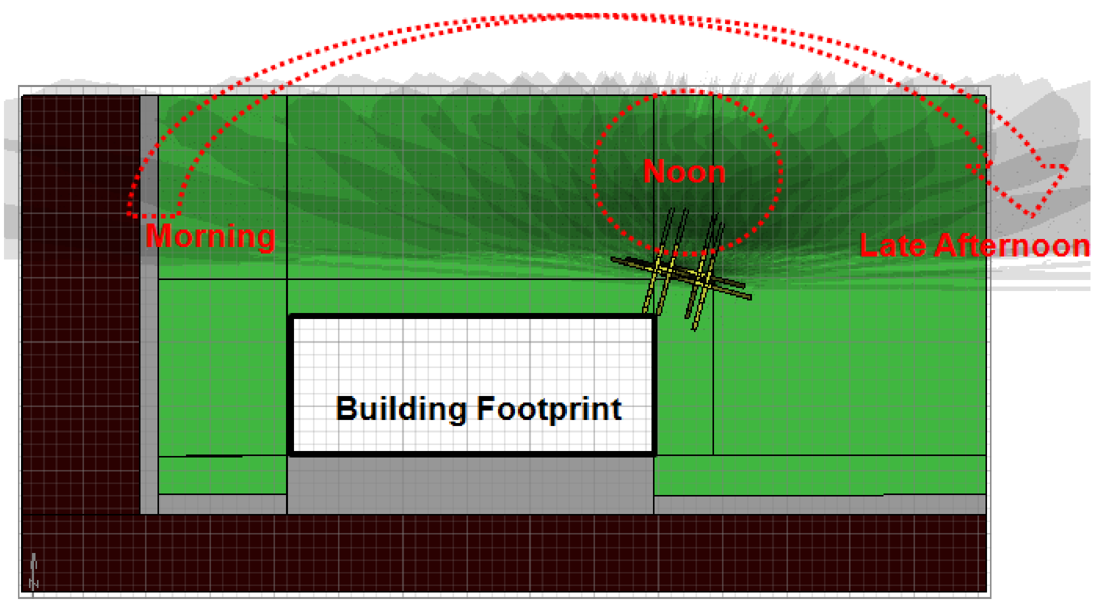


Figure 3.8: Daily shading pattern of existing trees in september 21st

The above simulation result shows there is no shading during the day in the backyard and on building facades.

Energy Impacts of Artificial Tree Planting

Now that we have studied the existing condition, it is best to know how to design and layout a landscape strategy to support our net-zero initiatives. Planting trees are part of any conventional building construction project and regardless of size and location there is a budget for landscaping. There are scientific studies supporting the idea that energy focused landscaping design strategies will reduce building energy consumption by some fraction. Simulations indicated that in cold climates, a 30% uniform increase in urban tree cover can reduce winter heating bills in urban areas by about 10% and in rural areas by 20% by reducing ambient temperature and wind speed. In a follow-on undocumented work, they estimated that the savings in urban areas can almost be doubled if evergreen trees are planted strategically on the north side of buildings so that the buildings can be better protected from the cold north winter wind [12]. Akbari performed parametric simulations on the impact of tree locations on heating- and cooling-energy use and found that savings can vary from 2% to over 7%; cooling energy savings were higher for trees shading the west walls and windows [12].

Trees effect energy use in buildings through both direct and indirect processes. The direct effects are:

1- Reducing solar heat gain through windows, walls, and roofs by shading

2- Reducing the radiant heat gain from the surroundings by shading

The indirect effects are:

1- Reducing the outside air infiltration rate by lowering local wind speed

2- Reducing the heat gain into the buildings by lowering ambient temperatures through evapotranspiration in summer

3- In some cases, increasing the latent air-conditioning load by adding moisture to the air through evapotranspiration

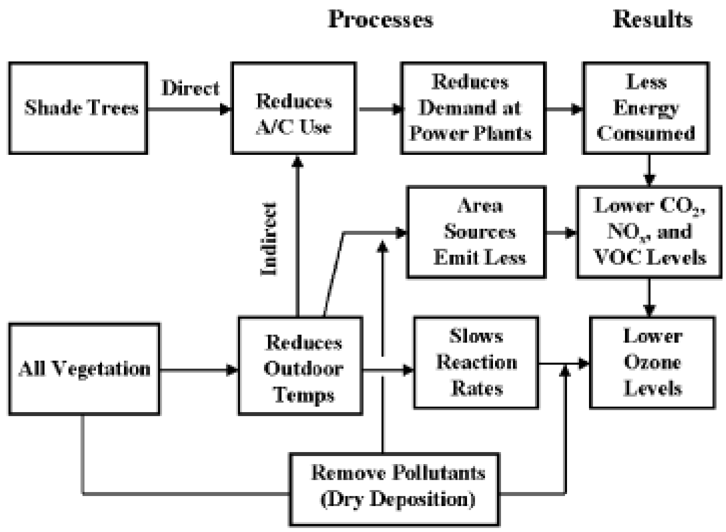


Figure 3.9: Direct and in direct of trees on energy and air-quality analysis [12]

In the case study project, we decided to to perform simulations of four different senarios of tree arrengments to quantify fractions of annual energy savings. The first senario had 30 foot tall evergreens at 5 foot on center within 10 feet of west building façade (35 feet long two stories height) with no glazing system. The building model is made of common conventional residential construction materials. Design builder is selected as the modeling tool because of its capability of quick modeling and the precision of its Energy plus simulation engine. Table 3.1 shows annual building cooling and heating demand reduction estimated by simulation in scenario one. A 0.77 % reduction in building cooling and heating load is not significant but it shows the effectivness of solar radiation on an opaque facde facing west. This number can be different depanding on the fraction of west façade area to total building facades area. In senario two, to the same building model we added to the 30% standard double glazed windows to the west façade area to observe the shading effects on west facades in need of natural lighting or in case of building code requirments. Results (Table 3.2.) indicates a 3.8% reduction in total annual cooling and heating demand. Results of senario one and two indicates that the effectiveness of shading on the east façade would be less due shorter radiation time in the morning. performance of simulation for senario 3 (east façade without windows) and Senario 4 (east façade with 30% glazing) are shown in table 3.3 and 3.4.

Table 3.1: Annual building cooling and heating load reduction (West façade, No Glazing)

Date/Time	Cooling Loads	Cooling Loads w/trees	cooling savings	Heating Loads	Heating Loads w/trees	heating savings
	kBtu	kBtu	kBtu	kBtu	kBtu	kBtu
1/1/2002	-0.9364281	-0.790525	0.1459031	21118.39	21167.78	-49.39
2/1/2002	0	0	0	14861.96	14932.84	-70.88
3/1/2002	-143.8758	-127.3514	16.5244	8800.675	8914.146	-113.471
4/1/2002	-1021.039	-977.2408	43.7982	1947.148	1997.928	-50.78
5/1/2002	-3973.755	-3812.153	161.602	139.5397	157.0138	-17.4741
6/1/2002	-11882.24	-11577.57	304.67	0	0	0
7/1/2002	-14745.35	-14317.32	428.03	0	0	0
8/1/2002	-23214.09	-22767.82	446.27	0	0	0
9/1/2002	-11798.76	-11522.24	276.52	20.5918	21.53885	-0.94705
10/1/2002	-1768.046	-1696.77	71.276	4521.105	4618.009	-96.904
11/1/2002	0	0	0	14868.48	14944.07	-75.59
12/1/2002	0	0	0	23479.63	23538.32	-58.69
total	-68548.09223	-66799.25573	1748.836503	89757.5195	90291.64565	-534.12615
Annual system load						
158305.612						
Annual system loads savings w/trees						
1214.71035						
Saving with tree shading percentage						
0.76731983	0.77%					

Table 3.2: Annual building cooling and heating load reduction (West façade, w/ glazing)

Date/Time	Cooling Loads	Cooling Loads w/trees	cooling savings	Heating Loads	Heating Loads w/trees	heating savings
	kBtu	kBtu	kBtu	kBtu	kBtu	kBtu
1/1/2002	-6.588245	-0.7668037	5.8214413	21335.06	21850.08	-515.02
2/1/2002	-0.9120108	0	0.9120108	14886.59	15388.02	-501.43
3/1/2002	-258.7449	-122.7501	135.9948	8641.231	9260.271	-619.04
4/1/2002	-1370.661	-982.2334	388.4276	1873.617	2151.332	-277.715
5/1/2002	-4913.281	-3795.024	1118.257	124.4479	200.6249	-76.177
6/1/2002	-13424.7	-11503.86	1920.84	0	0.6847349	-0.6847349
7/1/2002	-16310.88	-14179.63	2131.25	0	0	0
8/1/2002	-24858.73	-22660.1	2198.63	0	0	0
9/1/2002	-12851.84	-11389.01	1462.83	22.10943	27.69696	-5.58753
10/1/2002	-2192.647	-1645.822	546.825	4476.877	4960.495	-483.618
11/1/2002	0	0	0	14898.88	15427.4	-528.52
12/1/2002	0	0	0	23740	24303.05	-563.05
total	-76188.98416	-66279.1963	9909.787852	89998.81233	93569.65459	-3570.842265
Annual system load						
166187.796						
Annual system loads savings w/trees						
6338.94559						
Saving with tree shading percentage						
3.81432676	**3.80%**					

Table 3.3: Annual building cooling an eating load reduction (east façade, No glazing)

Date/Time	Cooling Loads	Cooling Loads w/trees	cooling savings	Heating Loads	Heating Loads w/trees	heating savings
	kBtu	kBtu	kBtu	kBtu	kBtu	kBtu
1/1/2002	-0.9364281	-0.8645992	0.0718289	21118.39	21173.38	-54.99
2/1/2002	0	0	0	14861.96	14934.78	-72.82
3/1/2002	-143.8758	-125.4947	18.3811	8800.675	8931.486	-130.811
4/1/2002	-1021.039	-976.8644	44.1746	1947.148	2004.357	-57.209
5/1/2002	-3973.755	-3807.153	166.602	139.5397	155.216	-15.6763
6/1/2002	-11882.24	-11564.15	318.09	0	0	0
7/1/2002	-14745.35	-14369.33	376.02	0	0	0
8/1/2002	-23214.09	-22756.03	458.06	0	0	0
9/1/2002	-11798.76	-11573.15	225.61	20.5918	21.19405	-0.60225
10/1/2002	-1768.046	-1713.111	54.935	4521.105	4603.164	-82.059
11/1/2002	0	0	0	14868.48	14918.58	-50.1
12/1/2002	0	0	0	23479.63	23549.62	-69.99
total	-68548.09223	-66886.1477	1661.944529	89757.5195	90291.77705	-534.25755
Annual system load						
158305.612						
Annual system loads savings w/trees						
1127.68698						
Saving with tree shading percentage						
0.71234808	**0.71%**					

Table 3.4: Annual building cooling and heating load reduction (east façade, with glazing)

Date/Time	Cooling Loads	Cooling Loads w/trees	cooling savings	Heating Loads	Heating Loads w/trees	heating savings
	kBtu	kBtu	kBtu	kBtu	kBtu	kBtu
1/1/2002	-1.863067	-0.8420858	1.0209812	21344.02	21814.47	-470.45
2/1/2002	-0.5849025	0	0.5849025	14870.39	15366.36	-495.97
3/1/2002	-214.1745	-122.7634	91.4111	8572.377	9262.239	-689.862
4/1/2002	-1294.692	-990.5778	304.1142	1835.559	2140.652	-305.093
5/1/2002	-4730.654	-3814.6	916.054	121.3996	197.5074	-76.1078
6/1/2002	-13290.49	-11527.94	1762.55	0	0.5172397	-0.5172397
7/1/2002	-16084.43	-14263.21	1821.22	0	0	0
8/1/2002	-24852.57	-22683.35	2169.22	0	0	0
9/1/2002	-12649.47	-11461.2	1188.27	23.07016	27.27241	-4.20225
10/1/2002	-2030.318	-1676.125	354.193	4476.388	4925.844	-449.456
11/1/2002	0	0	0	14975.14	15378.23	-403.09
12/1/2002	0	0	0	23680.41	24259.07	-578.66
total	-75149.24647	-66540.60829	8608.638184	89898.75376	93372.16205	-3473.40829
Annual system load						
165048						
Annual system loads savings w/trees						
5135.22989						
Saving with tree shading percentage						
3.11135542	3.10%					

A Conclusion to Site Design

In conventional low-rise residential design practice, which covers more than 90 percent of new and existing residential buildings, it is not practical to execute wind analysis and building energy simulation to determine the best orientation of building and trees unless the architect believes the existing conditions will significantly effects building energy consumption. Having a general knowledge of effectiveness of wind patterns, average monthly radiation in the project's area, and tree shading effects on annual building cooling load, alongside with knowledge of site design can be a positive start toward having a potential net-zero home. In our case study project, the goal is to use all of these data and strategies to achieve an optimum site design. Below are steps toward an energy smart site design strategy for the case study project:

- The site is relatively flat with a natural slope from southeast to northwest. With some grading, we can prepare a flat building pad for four units with maximum depth of 35 feet and 22.5 feet width for each unit.
- The ideal orientation for a passive solar home is along the east-west axis. In the site, due to the lot location (corner lot) and potential access from 15th street the ideal design is to layout buildings from west to east to maximize south face exposure for solar passive energy, daylighting, and also location of building driveways from low traffic road (15th street) for higher safety.
- The first unit parallel with State Street has a west façade with the biggest fraction with the rest of its exterior facades compared to other three units. There are two issues associated with this façade: noise pollution from State street traffic and westerly solar radiation. It is possible to reduce these problems by plating evergreen trees to work as a sound and solar radiation barrier. In our case, based on simulation results a line of tall trees (30 feet) can help reducing cooling loads for a few percent. The second obvious strategy is eliminating glazing system and design floor plans to receive natural lighting from south and north faces.
- No tall trees or plants on the north and south sides of building to block sunrays during heating season and potential natural ventilation during swing seasons.
- Light colored materials on the west and east facades to minimize heat observation during summer.
- The east side of the building site is only 10 feet wide and too narrow for tall and big trees plus the impact of energy savings are very low. In this case, in order to manage the budget we decide to limit our evergreen barriers only to west side.
- Planting 30 foot cypress trees for a residential project is very costly and would affect the project budget goals. In order to justify this issue it is best to use 8 to 12 foot trees and in a few years, the green wall will have its full performance, due to its rapid growth .

Figure 3.9 illustrates site plan preliminary design and energy savings strategies such as building orientation, unit's arrangement and accesses and tree planning.

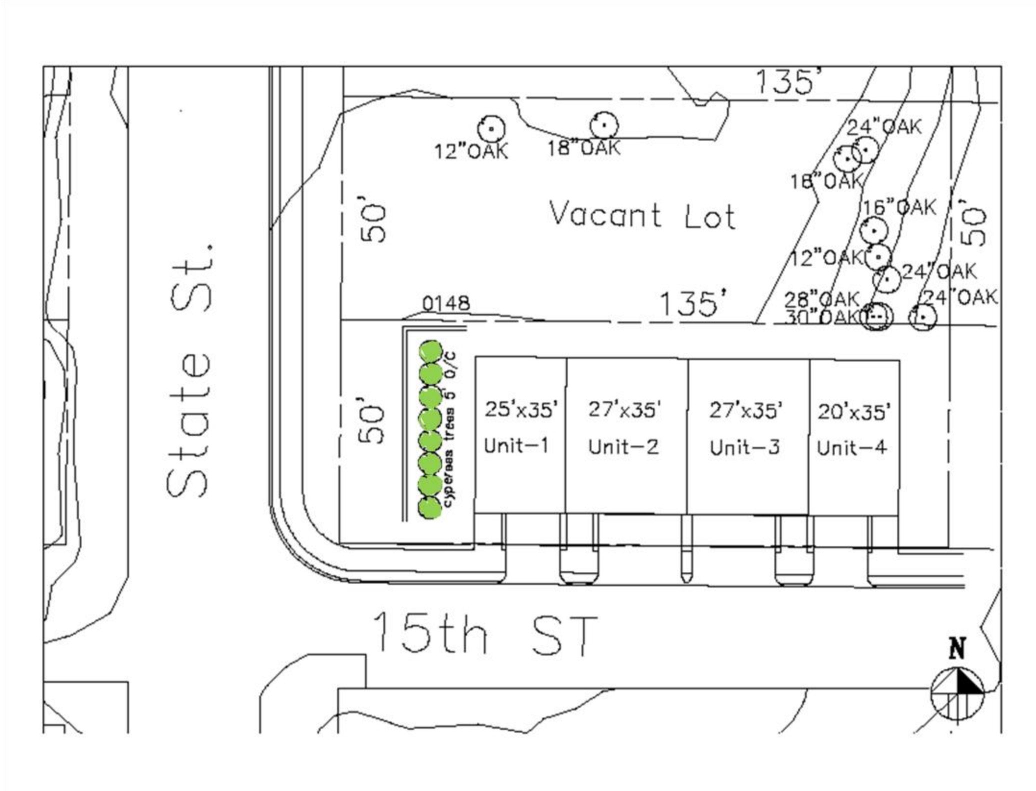


Figure 3.10: Site Plan Preliminary Design Strategies

CHAPTER 4

BUILDING DESIGN PROCESS

Schematic building design starts with guidelines drafted in an architectural program and developed throughout the design development phase. In this case study, the main focus will be on implementing building science strategies, simulation tools and green technologies into the building program and design process in a efficient and practical manor.

Building Program

As it has been described, the project is a quadplex townhouse building expanding from west to east based on the site design. The developer plan is to have live-work type units with attached car garages. Two bedroom units with one car garage and three bedroom units with two car garages having less than 2000 square feet of heated space for occupants. These types of attached residential buildings are very common in low-density urban neighborhoods and the option of live-work will makes it to a more attractive and marketable project in this area.

Space Zoning

The orientations of interior spaces for this project has been arranged based on market demand and the interest for these types of living spaces. Based on common strategies and building codes regulations in the case study project and site plan characteristics, each unit is includes three levels. The first floor includes the garage, foyer, and a workspace, the second floor covers a common sitting area, kitchen, and dinning space, the last level has bedrooms. This is a general building program for the case study project. These types of separation between spaces not only creates an acceptable level of privacy but also will help to manage energy consumption due to different time usage between each level. Separate HVAC and lighting schedules and control systems can breakdown the total building living area to three sections which most of the time would not be running simultaneously. Figure 4.1 shows a zoning architectural diagram of the case study project.

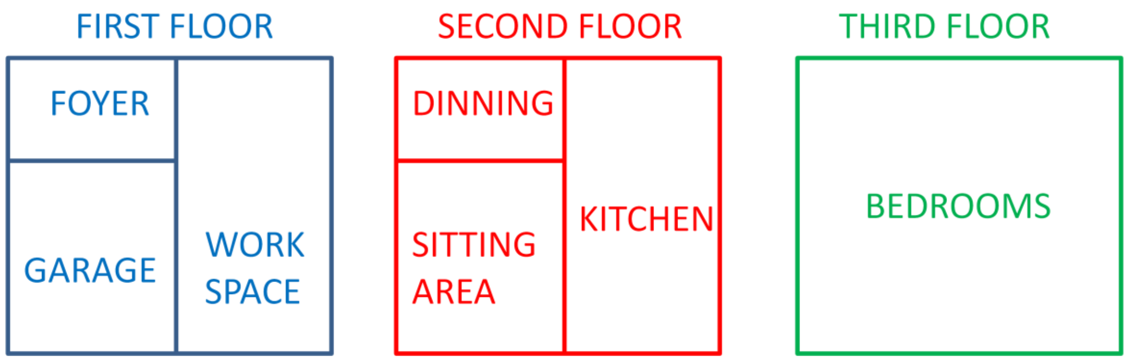


Figure 4.1: Zoning program of the Net-Zero case study project

In energy conscious projects, the architectural program not only should comply with important factors of building design and construction but also should support the reduction of building energy consumption. Proper zoning of interior spaces and schedule management would be an effective technique to support this. In our case study project, dividing each unit to three zones (levels) having separate usage schedule will support the use of building energy management while producing a marketable product for investors. The main challenge for designers is to design an acceptable and marketable home based on the project demographic while implementing energy consumption management and reduction techniques in their design.

Passive Solar Energy

Orientation of multiple spaces within a zone to observe solar radiation during heating season and proper use of natural lighting could be varied based on the climate zone, building type, and demographics. In the case study project, passive solar energy will effectively reduce heating loads during heating season. Our strategy to maximize this benefit is to place areas with higher usage during the day and with bigger air volume in south part of the building. An open floor plan will be beneficial to uniform heat transfer throughout the zone. Spaces like the main living area, workspace, and master bedroom are main candidates of south facing orientation but there are always some obstacles and limitations for the best case scenario. Building orientation, vertical-horizontal exterior and interior accesses, building codes and regulations and sometimes market demand for specific floor plan layouts contribute to the inability of designers to have an ideal location for a specific space. In the net-zero case study project, building access is only from the south side which dictates the location of garages and the units entrances in ground floor. Figure 4.2.a demonstrates the layout of the first floors for the two and three bedroom units. The workspace is located in north side of units with stairs located in the middle.

Figure 4.2.a: First floor layouts and site access to the building

Based on the zoning diagram the second floor covers all the common areas of the units. The living room, kitchen, dining room and powder room are layout in the second floors. These spaces are normally in use after working hours during the week for working families and almost all day for others. The concept of open floor plans allows solar radiation in through the south face to be distributed throughout the 2^{nd} floor as well as for natural lighting from south and north facades. Spaces with less need for natural lighting and thermal comfort like the powder room and stairs are located in the middle of floor plans to give the priorities to living rooms and kitchens. In two bedroom plan the living room is located on the north side to have a view of the backyard and provide diffuse lighting all day. The three bedroom units' living room is in the south side with a covered porch facing north to the backyard. The idea behind these design differences is improving marketability of the units. Figure 4.2.b shows the preliminary design of send floor plans.

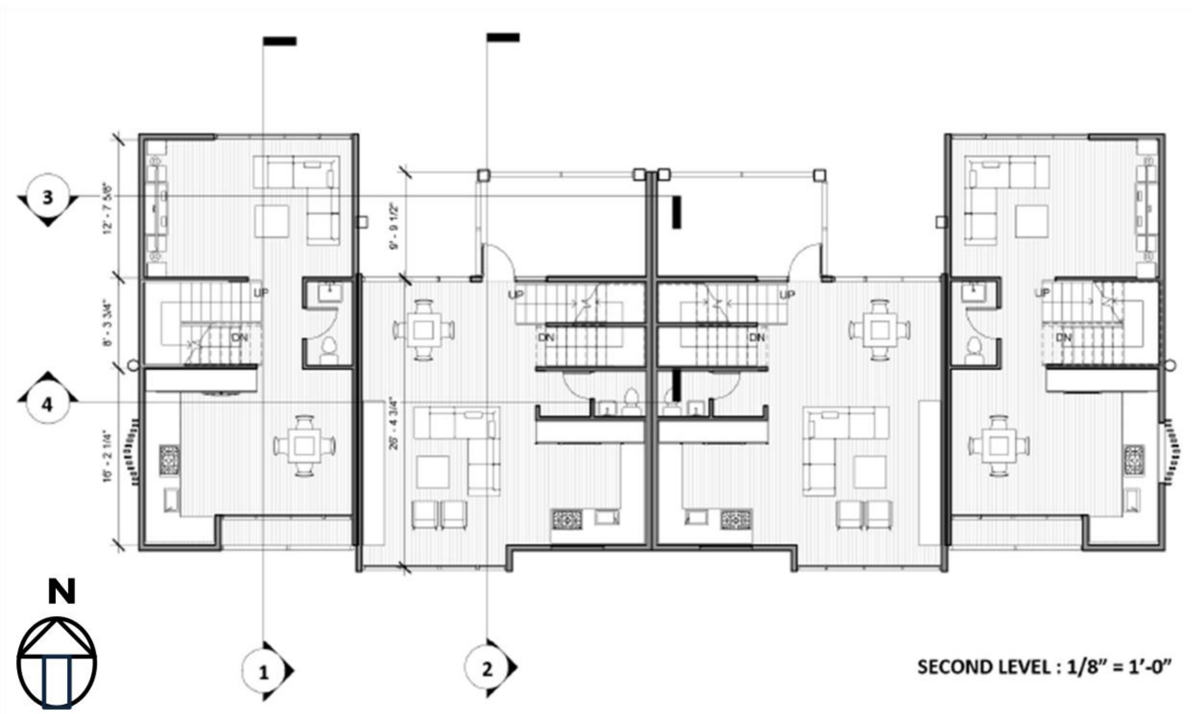


Figure 4.2.b: Second floor plan layouts

The last level is dedicated to private spaces of the home including bedrooms, a laundry room and full bathrooms. In both floor plans, master bedrooms are located in the south side with a private balcony for two bedroom units. In the next chapter, I discuses the methodology of the sizing overhangs and balconies of the south façade. The probability of the master bedroom to be occupied is much greater than the secondary bedrooms due to the number of occupants. In this scenario, the master bedroom always will be a conditioned space and winter solar heat gain could reduce the heating need of this room during the day. Secondary bedrooms on the other hand may not have occupants, therefore there is no need for them to be conditioned constantly. This theoretical design strategy might be applicable during occupancy of some of these units. Figure 4.2.c shows the preliminary design of the third floor units.

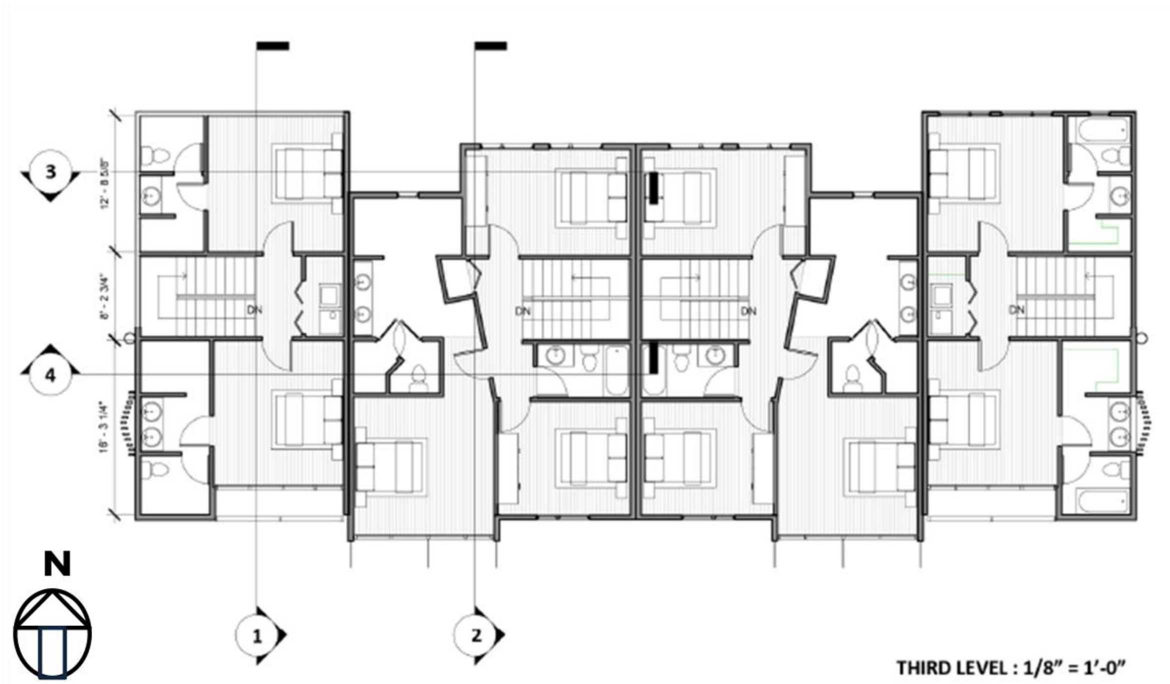


Figure 4.2.c: Third floor plan layout

Natural Lighting

Natural lighting is one of the most important aspects of building design in many ways. Historically architects were always looking to bring light into their spaces. Light is a symbol of life and represents the beauty of the outside world. Tadao Ando expresses his personal image of light this way: light is the origin of being. Light gives, with each moment new form to being and new interrelationship to things and architecture condenses light to its most concise being. The creation of space in architecture is simply the condensation and purification of the power of light [13].

A major factor for a marketable home is its ability to capture natural light and have an acceptable exterior view to the surrounding environment, however finding the trade-off between the ratio of opaque wall and fenestration is a challenge for the optimization of building heating-cooling load and artificial lighting energy consumption. This optimization process can be very complex for commercial buildings but for residential structures can be simplified to a systematic procedure. The following general strategies will support the desire of homeowners for natural lighting and building views while consider the idea of lowering building cooling-heating load.

- Place the main living spaces of the house such as the main sitting area, kitchen, and workspace in the south face of the building with sufficient glazing area. From a daylighting standpoint, this is desirable because direct solar radiation received by the south façade is easier to control to prevent excess solar gain, is relatively uniform, and is necessary for solar heating strategies [14].
- Control daylighting with external overhangs, canopies, concealed balconies and light shelves; control direct sun radiation, glare and uniform distribution into space for south facing spaces.
- Secondary bedrooms can face north to avoid morning radiation. The nearly constant diffuse skylight availability on the north façade is advantageous for uniform and soft daylighting [14].

- Secondary bathrooms, staircases, storage spaces, laundry room and the areas that occupants don't spend a lot of time in can be designed with no or small window systems and can be placed in the west and east side of building. This strategy can reduce the heating-cooling load of the building.
- All of these recommendations are considered for an ideal case and cannot be achieved in all cases. The building orientation and shape, microclimate and cultural differences may change all of these suggestions. In large-scale residential projects daylighting simulation analysis will be the best strategy to achieve desired natural light and view for each space.

In the case study project, we have sufficient natural lighting from south and north façades and have avoided windows on west and east facades in order to have maximum control on direct solar radiation, glare, and more uniform lighting distribution. Figure 5.2. shows the finalized floor plans of the case study project. The process of designing the floor plans are not the subject of this project, nevertheless it is very important to acknowledge the importance of architect's knowledge and skills to design a home with optimum result of natural lighting and energy demand.

In the beginning of the case study elevation design, we have decided to start with maximizing the glazing of the south façade and various window sizes for the north facing spaces depending on their area and functionalities. This can be the preliminary setting for windows orientations and design in the model base simulation.

In the simulation process, one of the sensitive parameters besides U-value and SHGC is the glazing system area. Final decision about the window dimensions depends on the results of simulation and optimization process of building energy consumption.

Natural Ventilation

Implementation of natural ventilation into building energy consumption is neither easily applicable with current tools nor desirable for small-scale residential projects. The level of uncertainty and unpredictability of hourly wind pressure and direction make this natural free energy an unreliable resource to be considered as part of energy simulation analysis. This statement can be interoperated in a different way for regions with steady wind pressure during cooling period. Natural ventilation could become an important renewable energy source and drastically reduce building cooling load and support net-zero homes initiatives.

In the case study project, the regional location (Atlanta) does not support the idea of natural ventilation due to limited hours of wind and its characteristics. On the other hand high humidity during the summer creates a major issue for natural ventilation. All of these barriers for natural ventilation would not cancel-out the advantage of natural ventilation during the swing seasons (between 10-20 days) for the region. Our design approach to natural ventilation for the case study project is to provide operable openings in north and south fenestrations allowing occupants to manage airflow into the space based on their desire for fresh air and exclude possible energy savings of this process from energy simulation. The energy reduction benefits of natural ventilation in the project can be considered as a positive factor supporting the net-zero initiative.

In our design, we created openings in north and south facades to let the airflow through the floor without being blocked by interior walls. Specifically in second floors and in the third floor bedroom doors are facing each other to let the airflow from north to south when they are open. Figure 4.3 shows natural ventilation prediction that may accrue during swing seasons.

Figure 4.3.a: Possible airflow via window openings on the first floor

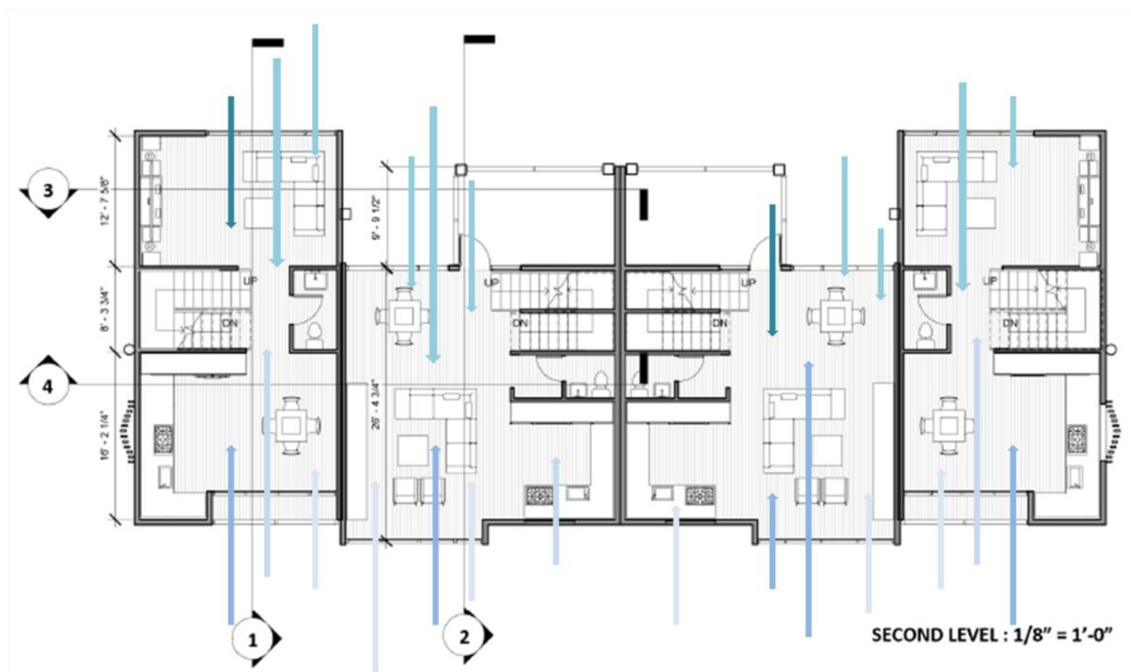


Figure 4.3.b: Possible manual natural ventilation for the second floor layouts

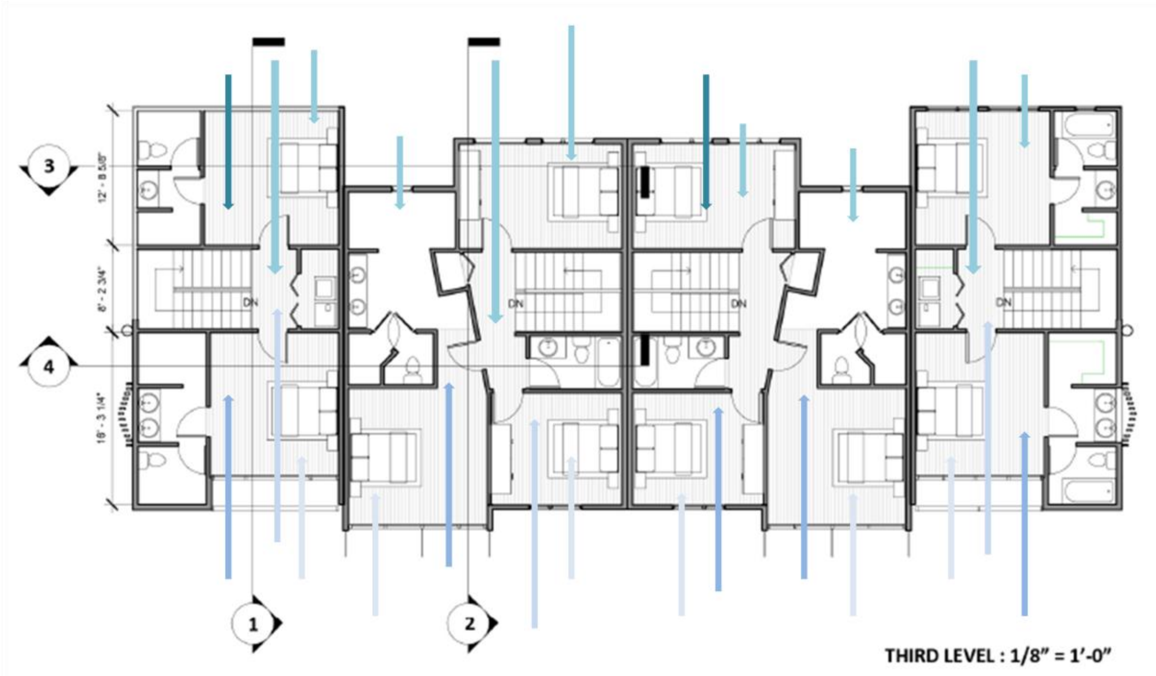


Figure 4.3.c: Possible manual natural ventilation for the third floor layouts

CHAPTER 5

BUILDING ENERGY DEMAND ANALYSIS

The performance of low-energy or net-zero energy buildings need to be verified and evaluated by simulation analysis. In the case of low-rise residential buildings, the simplicity and affordability of these tools are important factors in this design environment. Time and budget limitations are critical factors that need to be carefully addressed in projects with sensitive parameters that need extensive testing and evaluations. Currently there are many sophisticated programs and tools available in the market for green building analysts to use for evaluating different parameters of building and give them feedback to support building energy reduction, improving indoor air quality, and thermal comfort. Most of these tools are exclusively designed for large-scale commercial projects and need a professional energy analyst in order to give feedback to the design team. A program such as Energy Plus will have a higher level of sophistication compared to some simplified tools, but the design cost and simulation time increase in using these types of programs cannot be easily justified in small-scale projects. In order to overcome these obstacles, the Georgia Tech building technology program has developed a building energy performance calculator exclusively designed for estimating energy performance of residential buildings. This tool is based on CEN/ISO standards.

Georgia Tech. Building Energy Performance Calculator

The residential version of The Building Energy Performance Calculator is a result of an ongoing effort by the Building Technology group in college of Architecture at the Georgia Institute of Technology. The fundamental design of the calculator is based on the determination of the thermal energy demand of a building with a special regard to a normative treatment of heat gains, loss, occupancy, controls, and system efficiencies [15].

The total building consumption is determined as the sum of energy uses for heating, ventilation, lighting, pumps, cooling, (de)humidifying and preparation of domestic hot water by building installations [16]. The performance indicators of this normative calculator calibrated by measurements on actual buildings with specific and relevant operational schedules. Although the resulting value cannot be taken as an accurate measure for an observable physical variable, and the simplification of the experiment allows the derivation, the approach is accurate enough to estimate the expected energy performance [17]. The point of calculator is to compare the effects of different design choices, not accurate point predictions. The normative calculator has a benefit of being a user friendly and easy tool with the goal of supporting low energy consumption home design.

Sensitive Parameters Analysis and Annual Energy Demand

The optimization of building components thermal and physical properties should not be a complex mater. Designers can use high performance materials and systems in their project and lower the building energy demand as much possible. While materials and systems can be evaluated by simulation tools, in reality barriers such as high initial cost, limited production, uncertainty in their durability, and public acceptance of new technologies make the use of these products challenging.

In the case study project, the main goal is to design a building that can be sold in the current market alongside new conventional buildings. The design team goal is to balance the cost by reducing the construction budget of some of the cosmetic components of the building and add it into the budget of green technologies.

The data input section of The Building Energy Performance Calculator includes eight sections. General building information specifies the area and volume of different building area. Our assumption at this point is preliminary floor plans are complete and there are no major changes in the building area and number of rooms. The second input section specifies the indoor set point temperature for cooling and heating seasons. This can be set based on a standard or it can be set based on the desire of occupants. In the project, the cooling set point is 24c while 21c is set for the heating period. The envelope area section specifies the area of the opaque walls, windows and doors area. Due to the lower U- value and allowance of direct solar heat gain, the area of fenestration is a very sensitive parameter to be optimized in buildings. Material is the most important section in simulations. The input values of this section depends on the type of construction, budget and the location. The building system section is made of four major parts: ventilation, cooling and heating, lighting and domestic hot water. All of these systems will contribute directly to building energy consumption. Higher efficiency and proper design of systems can significantly reduce the building energy consumption. The energy generation systems section computes monthly on-site energy production for the designed system. The energy carriers section specifies the primary energy source for electricity, DHW, and heating. The last section provides the annual cost of energy consumption and on-site energy production.

The optimization strategy for the case study project is creating a base case simulation model, known as option one and analyzing sensitive building components and systems with different options individually to find the best-case scenario. This strategy is a back and forth process and could be applied in different ways depends on the sensitivity of project and analyst's methodologies.

Base Simulation Model

The base simulation model is created according to standard construction details, materials and systems in the case study region. The purpose of creating a base model is to estimate the annual energy consumption of conventional construction practice for the case study project. This way the designer can identify the role and sensitivity of each individual component and system in total energy consumption. The methodology would help the analyst to pursue his/her goals in reducing energy consumption in more effective and practical ways. Keep in mind that in this part of project, the emphasis is only on reducing building energy demand and we will not work with the systems at this point until we can minimize the building energy need to its possible lowest level. In the chapters following the mechanical system analysis and selection, we will continue with simulation and analysis of sensitivities building system parameters.

Figure 5.1 represents the simulation results of cooling and heating demand of the base model with The Building Performance Tool. Besides the advantage of quick energy assessment, this program is able to generate multiple tables and diagrams, generating monthly breakdowns of direct solar heat gain, heat transfer of opaque walls, roof, and ventilation and internal heat gains of the design.

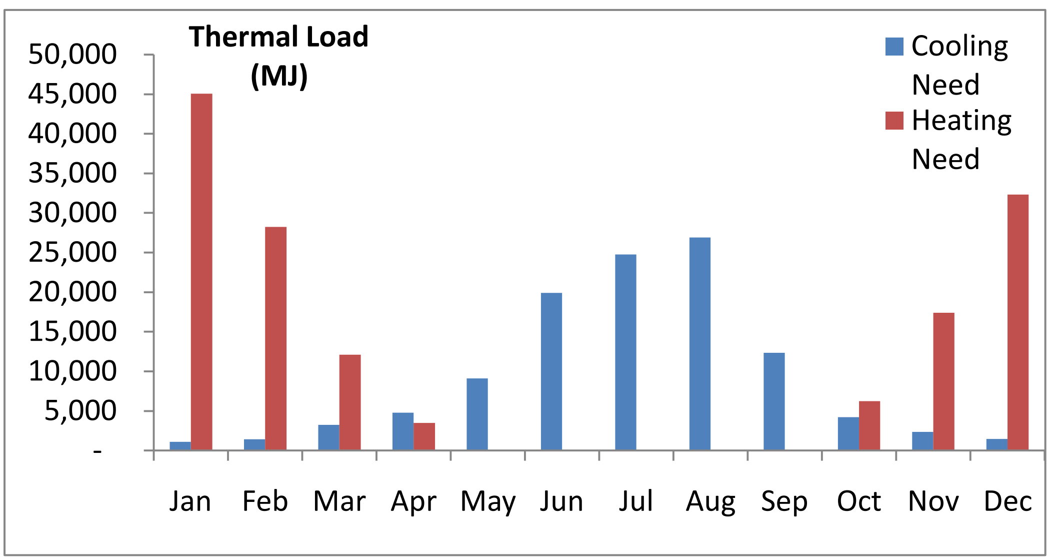


Figure 5.1: Monthly cooling and heating demand of the base model

These outputs allow the analyst to examine different parameters of the building such as windows area and its thermal and physical properties, different wall and roof assembles, and external overhangs to find the most optimum option based on the budget and design criteria. In the case study model, the design team extensively examined all of the parameters to lower the average annual energy demand per square unit. Figures 5.2.a, 5.2.b and 5.2.c show the properties of the building components used in base model, building energy need per unit floor area, and solar heat gains through glazing system in each facade.

Material	
Roof U-value [W/(m^{2}K)]	0.163
Roof - Emissivity	0.462
Opaque Wall U-value [W/(m^{2}K)]	0.331
Opaque Wall Emissivity	0.450
Window Type 1 U-value [W/(m^{2}K)]	2.780
Window Type 1 Solar Transmittance	0.500
Window Type 2 U-value [W/(m^{2}K)]	
Window Type 2 Solar Transmittance	
Door material U-value [W/(m^{2}K)]	2.780
Envelope Heat Capacity (J/(Km2))	

Figure 5.2.a: Material inputs of the base model design

[E.1] Energy Need

$Q_{design,nd}$ [kWh/m^2/yr]	**127**	**Q_{ref_nd} [kWh/m^2/yr]**	**151**	**EPCnd**	0.84

Figure 5.2.b: Average energy need of the base design, compare to the reference

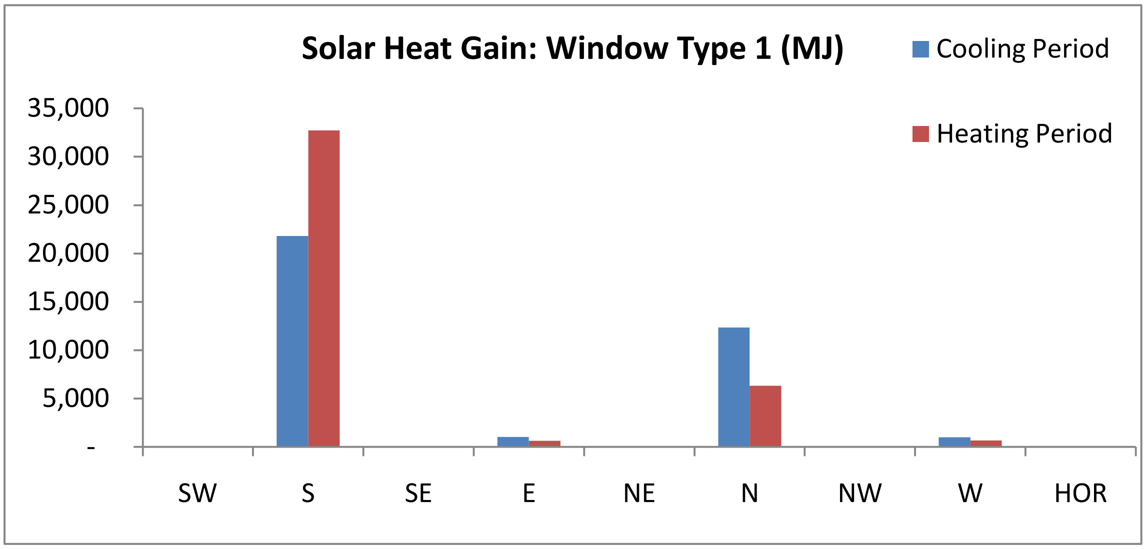


Figure 5.2.c: Solar heat gain from different facades through glazing systems

Energy Demand Reduction Strategies and Process

Based on the ability of the simulation tool to generate detailed results of building energy demand, it is possible to identify the effectiveness of different options in every category of building design.

During the design of the case study project, the design team carefully examined different scenarios of building assemblies and details based on their availability, price, payback period, and benefit to the project before finalizing any design decision. This process is an ongoing procedure during the design phase to achieve an optimum design based on available resources. In the case study project, the overhangs were carefully sized to maximize solar radiation into the space during heating season while blocking direct radiation during cooling season. Pictures 5.3.a and 5.3.b show how properly sized overhangs and concealed balconies control the direct radiation during a year on the south façade. The space receives maximum solar radiation in winter due to the lower solar incident angle and optimized overhang sizes. The thermal properties of windows, opaque walls, and roof assemblies, the building infiltration/ventilation load, and other internal loads are the main categories that could affect energy demand of the building.

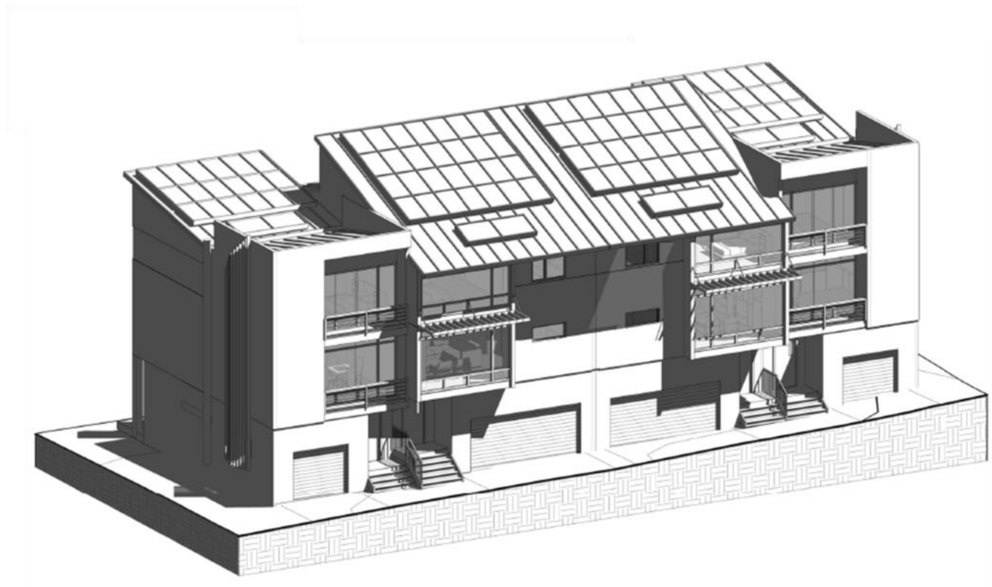


Figure 5.3.a: South face fenestration system is fully shaded on June 21 at solar noon

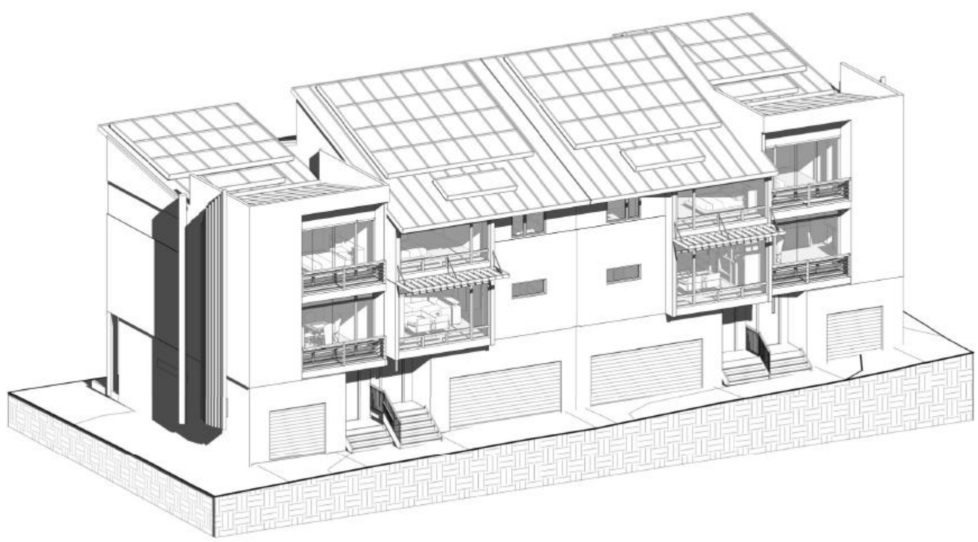


Figure 5.3.b: South face fenestration system on December 21 at solar noon

In order to demonstrate the process of energy demand reduction in the base model, the glazing type assessment can be a good example.

The thermal property of the base model window is based on the average existing glazing system in the residential market. In the past few years with the support of government incentives and green intuitive movements, manufacturers are producing high performance fenestration systems both in the residential and commercial industries. The federal tax break for homeowners upgrading their window system to government's benchmark level is lowering the price and payback period time of high performance windows to a practical level.

We have chosen two upgrades and one standard window from a production line of a manufacturer to examine the effectiveness of upgrading windows on building solar gains. The window type 2 has a U-value of 1.987 W/m2K with solar transmittance of 0.32 and type 3 window have a U-value of 1.533 W/m2K solar with solar transmittance of 0.23. Below is the solar heat gains result for all three options.

Table 5.1: Annual solar heat gain (MJ) of windows option 1, 2, and 3 during cooling & heating seasons

Solar Heat Gain (MJ)				
	South (MJ)	East (MJ)	North (MJ)	West (MJ)
Window 3 Heating	**15,055**	**301**	**2,906**	**304**
Window 3 Cooling	**10,033**	**478**	**5,679**	**459**
Window 2 Heating	**20,947**	**419**	**4,043**	**423**
Window 2 Cooling	**13,959**	**665**	**7,902**	**639**
Window 1 Heating	**39,275**	**785**	**7,580**	**793**
Window 1 Cooling	**26,173**	**1,247**	**14,816**	**1,198**

According to the results of table 5.1, there are significant improvements between option 1 (window 1) and 2 (window 2) in solar heat reduction during cooling season. It is an almost 50% reduction in solar heat gain during the cooling season. Making a decision at this point could not be possible without considering the fact that we need to maximize heat gain during the heating season from the south face. Improving thermal properties will reduce heat gains during the cooling season as well as the heating season. Table 5.1 indicates that the option 2 window can be the best option for north, East, and West facades due to its affordable price and significant reduction in heat gain during summer. In the south façade, solar heat gain increase during winter and reduction during summer requires additional strategies to support solar passive home strategies.

- First, Analysis of overhang shading effects on the solar heat gains for south facing windows.
- Second, considering a fourth type of glazing with low U-value of 1.7 W/m2K and higher solar transmittance (0.5) to allow solar radiation during winter

Table 5.2 illustrates the results of overhang and the 4th glazing system on the south facade.

Table 5.2: Windows performances with different overhang angels

south face	win 1	win 2	win 3	win 4	
heating	**39,275**	**20,947**	**15,055**	**32,729**	No Overhang
cooling	**26,173**	**13,959**	**10,033**	**21,811**	
heating	**19,637**	**11,829**	**8,502**	**5,040**	Overhang Angle 60
cooling	**13,087**	**5,624**	**4,042**	**3,157**	
heating	**29,063**	**15,501**	**11,141**	**5,040**	Overhang Angle 45
cooling	**19,368**	**10,330**	**7,424**	**3,157**	

Simulation results indicate that window 1 allows the maximum positive solar heat gain during the heating season although it adds almost 26,000 MJ to the cooling load. Looking back at Table 5.1 shows the same glazing system for the north façade adds 14,000 MJ to the cooling load, via diffuse radiation. The area of the glazing system of the north façade is approximately two square meters less than the south side. This analysis indicates that window 1 without overhangs will contribute around 12,000 MJ to the building cooling load while reducing the heating load by 40,000 MJ. From the design point of view, direct solar radiation during summer time will cause glare and reduce the comfort level inside the space. In Table 5.2, window 1 with an overhang angle of 60 degrees from window center shows a 13,000 MJ addition to the cooling load. This number is close to the solar heating gain from the north façade, which suggests, it is the result of diffuse solar radiation since overhangs eliminate majority of direct solar radiation heat gain. Solar radiation heat gain is not the only factor that needs to be considered in glazing type selection. Heat conduction through fenestration is directly affecting building cooling and heating loads. Window type 2 offers low U-value for the window with small fraction price increase in window package system.

In the case study project, the performance results of all the remaining building parameters has been evaluated with the building energy performance calculator similar to the process of glazing system selection. In order to make realistic decisions, designers should have an extensive knowledge of building physic, architecture, construction methods, and cost estimating (or have a support team of experts).

Reduced Energy Demand Simulation Results

A logical method for traditional residential construction to achieve net-zero energy balance is reducing energy demand as much as possible before drawing plans for any types of energy efficient building systems. Similar to the glazing systems analysis of other building assemblies and components choices should be tested with the simulation tool to select the best design. Here is a quick overview of some of these details and design choices that design team considered for the case study project.

- Advanced wood framing method is part of the EPA energy star program using 2x6 wood studs 24 inch on center instead of the conventional 2x4 16” o.c. framing method. This method reduces thermal bridges and allow more space for thicker insulation. The material cost of advanced framing is approximately the same as conventional method. The only current disadvantage of this method is slower construction process due to unfamiliarity of sub-contractors with the method.

- Using advanced high performance insulation materials (closed-cell polyurethane) instead of batt insulation in for exterior walls, ceilings, and roof. Polyurethane is a closed-cell foam insulation material that contains a low-conductivity gas (usually hydrochlorofluorocarbons or HCFC) in its cells. The high thermal resistance of the gas gives polyurethane insulation materials an R-value of around R-7 to R-8 per inch [18].
- Low-emissivity roofing materials (0.1) with high reflectivity (0.9) provides an effective radiant barrier during cooling season. Some studies show that radiant barriers can lower cooling costs between 5%–10% when used in a warm and sunny climate [18].
- Reducing air infiltration and leakage to minimum level with Airtight Drywall Approach (ADA) may reduce cooling and heating loads up to thirty percent. The typical procedure for ADA is to seal any seams and joints where the foundation, sill plate, floor joist header, and sub-floor meet [19]. DOE's reports shows new construction with the ADA method has 0.67-1.8 air changes per hour (ACH) compared with conventional new construction with 2.23-2.59 ACH. Test measurements of airborne contaminants in an ADA- or SCS-detailed building (including those with mechanical ventilation) found that the reduction of air infiltration did not diminish the indoor air quality significantly [19]. However, for the purpose of healthier indoor air, it is recommended that a heat recovery ventilator (HRV) or Enthalpy Recovery Ventilators (ERV) be installed in an airtight home for proper ventilation and better indoor air [19].

Implementation of these systems and details into the case study project alongside with scenario analysis supported by the simulation tool resulted in a building design with low energy demands based on available financial and technological resources, which can be marketed competitively with conventional construction with advantage of being a low-energy or net-zero energy home. Figure 5.4 illustrates the monthly cooling and heating demand of optimized case study project compared to the base model.

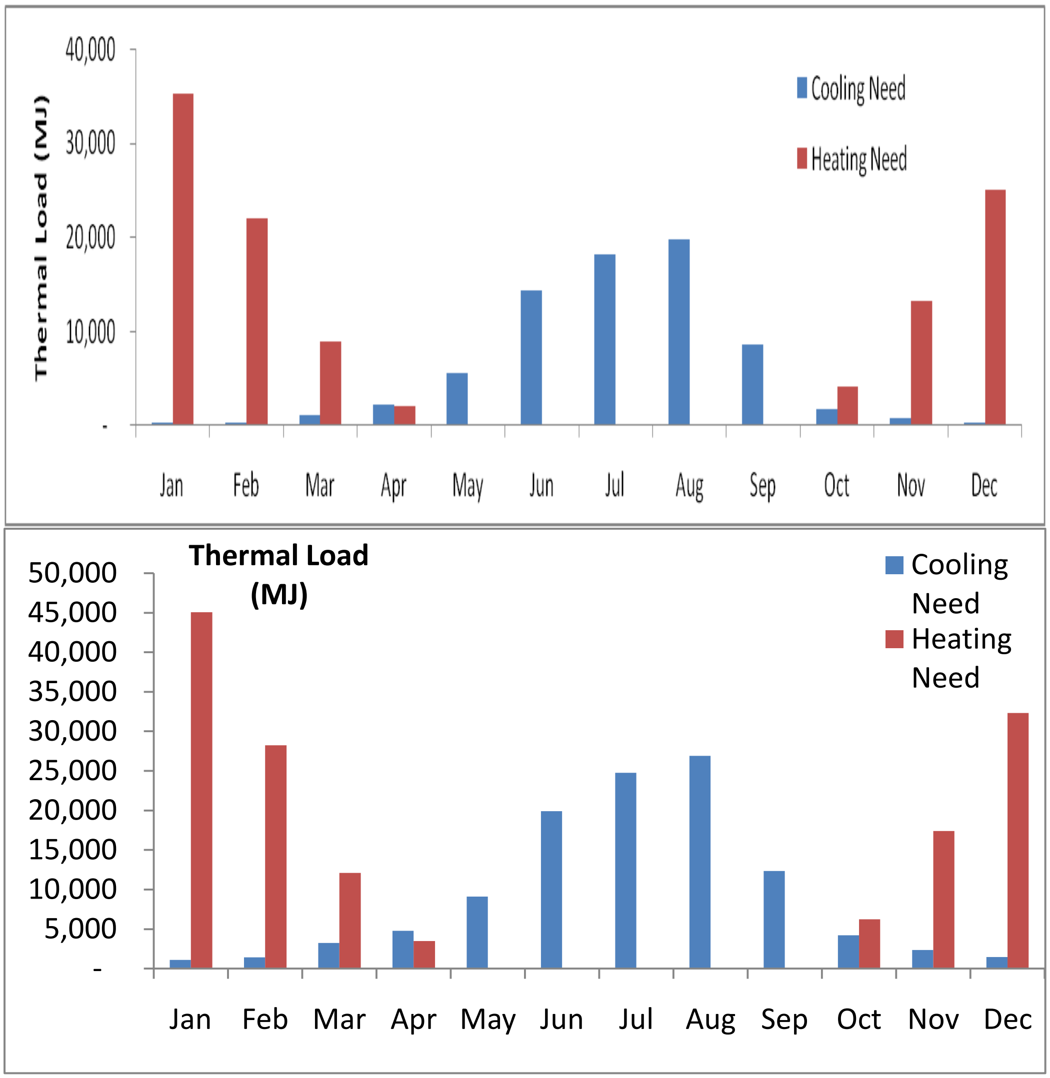


Figure 5.4: Simulation result of energy demand of optimized design (above) compare to the base model simulation results (below)

Improvements in energy demand reduction is enough to be supported by on-site energy production. Figure 5.5 is the result of finalized design simulation. Simulation results indicate that the energy need of the building is reduced from 127 kWh/m2/yr to 88 kWh/m2/yr. This is approximately a 30% reduction in building energy demand obtained by implementing available high performance materials and technologies and incorporating simple building science and tools into daily design process.

[E.1] Energy Need

$Q_{design,nd}$ [kWh/m^2/yr]	**88**	**Q_{ref_nd} [kWh/m^2/yr]**	151	**EPCnd**	0.58

[E.1] Energy Need

$Q_{design,nd}$ [kWh/m^2/yr]	**127**	**Q_{ref_nd} [kWh/m^2/yr]**	151	**EPCnd**	0.84

Figure 5.5: Average annual energy need of optimized design per square meter (above) compared to average annual energy need of base model (below)

CHAPTER 6

BUILDING SYSTEMS

Building systems provide comfort for occupants in buildings. In average buildings, electricity and natural gas are the main sources of energy for building systems. The primary focus of this methodology until this point was on reducing building thermal load; now building systems selection and energy performance analysis are important steps to insure maximum reduction in building utility energy consumption. Over-sizing building systems can have negative impacts on building annual energy consumption as well as thermal and visual comfort of occupants. Selection of systems in residential buildings depends on several important factors.

- Building Type
- Climate Zone
- Construction Budget
- Building Codes
- Building Site Demographic
- Energy Efficiency of system
- Annual Maintenance Costs of the System
- Available Tax Credits

Consideration of these factors supports the process of building system selection. Priorities of these factors are vary in different cases, and may result in selecting different systems for similar projects.

HVAC Systems

Residential heating and cooling system selection are based on priorities in building systems selection factors. In the case study project, the building is a low-rise townhome unit. The building has three levels with separate zones. This type of floor plans supports the idea of having separate HVAC units for each floor. Since Atlanta has hot and humid summers and cold winters, the system needs to operate efficiently in both heating and cooling seasons. Ducted heat pumps with backup electric resistance are the most common systems for this type of climate. Due to higher demand for this type of system, they are more affordable compared to other systems. Despite the popularity of this system, there are a few drawbacks. Duct systems leak due to poor installation, and complications of running ducts between floor joists and significant price increase for systems with higher efficiency support the idea of using a more flexible and efficient HVAC system. Ductless heat pumps are ideal choices for condominium and multi-family home projects. There are many advantages in this type of system that makes it a better choice.

- Saving space by eliminating air-handling units and running ducts
- Up to eight inverters for current models per heat pump with individual remote controls
- High energy efficiency (up to 22 SEER)
- Quiet operation
- High thermal comfort level

There are also some setbacks for this system.

- Small air filtration system
- Uneven air distribution in large rooms
- Unprecedented look of interiors

Based on these evaluations, high efficient ductless heat pump system could be an ideal choice for townhome units with limited heated area.

ERV Systems

Most of the new and existing homes in the US do not have ventilation system. Conventional air handling units circulate indoor air without adding outside air. Exhaust fans are the only sources for out-side air by creating negative pressure and suction of air from unwanted places like building cracks and other uncontrolled openings. Recently, new homes have a tighter envelope to save energy and minimize passive air leaks. This change requires a proper ventilation system to support healthy indoor air quality and prevent allergies and respiratory problems for occupants. Energy Recovery Ventilator (ERV) systems solve this by supplying air to replace exhausted air and help to balance air pressure within the home. They usually use two ducts, one to exhaust stale air and the other to supply fresh air from outdoors. This process also help to keep the pressure balanced in the house. Low ventilation rate and continuous run ensures chemicals such as volatile organic compounds (VOC) and other pollutants from cleaning fluids and building materials are vented out and replaced with outside air.

Energy Recovery Ventilator (ERV) provides a tempered air supply, humidity control, and a balanced amount of exhaust to help maintain neutral pressure throughout the home [20].

ASHRAE 62.2 standard is one of the main sources for residential ventilation and indoor air quality design. Based on its requirements, we have selected an ERV unit for

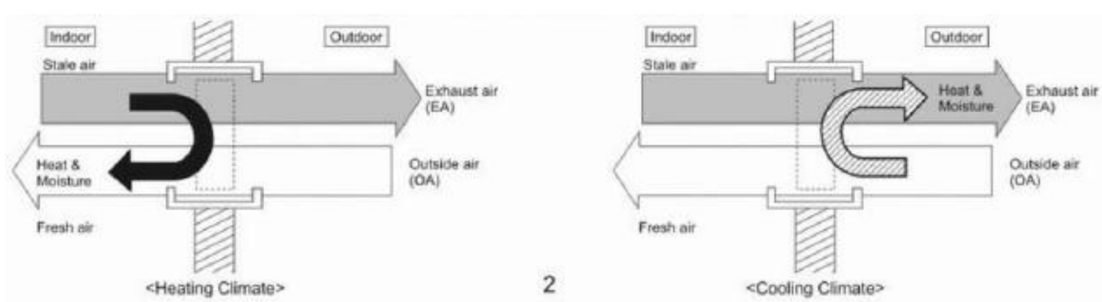


Figure 6.1: Concept of air exchange in an ERV system

the case study project and implemented the system specification in the simulation model. The result of simulation shows significant energy saving by reducing energy loss through infiltration. ERVs have the ability to regulate humidity as well as the temperature of incoming air depending on the volume of airflow and the temperature of the outdoor air, ERVs typically recapture 60-85% of the outgoing air's sensible heat - after accounting for the unit's own energy use. Average efficiency units can reduce heating energy consumption by 15% [21].

Domestic Hot Water Systems

In current new buildings, DHW energy consumption is a big portion of total building energy consumption, being the second largest energy consumer in homes. Studies shows water heaters consume 20% of the total energy consumption of homes on average. In the base model building, the water heater is estimated to consume 29% of annual building energy. Figure 6.2. illustrates the base model annual energy consumption breakdown. In case of a net-zero building minimizing or eliminating water heater energy consumption would be a breakthrough toward becoming energy neutral.

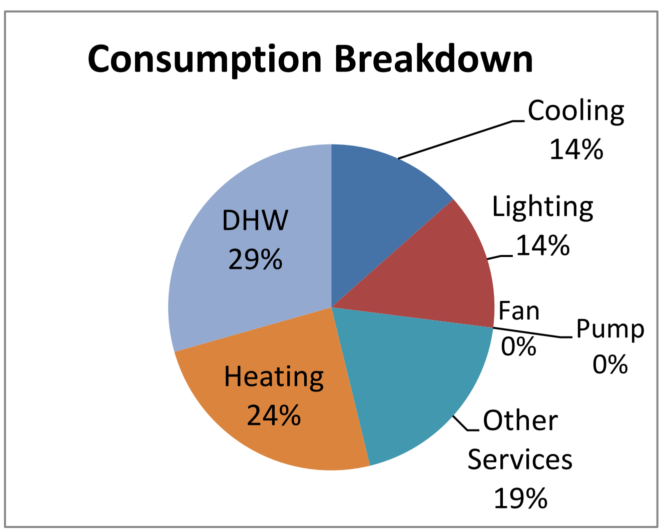


Figure 6.2: Base model building energy consumption breakdown

Reducing energy consumption for DHW can be challenging if the green package budget is limited. Products like water heater blankets can reduce energy usage up to 10%. Tankless water heaters can save energy depend on the number of households. For homes that use 41 gallons or less of hot water daily, demand water heaters can be 24%–34% more energy efficient than conventional storage tank water heaters. They can be 8%–14% more energy efficient for homes that use a lot of hot water—around 86 gallons per day. You can achieve even greater energy savings of 27%–50% if you install a demand water heater at each hot water outlet [22]. Simulation results of the case study shows achieving net-zero status is not possible with tankless systems.

Modern solar water heaters have reached an acceptable level of performance in recent models. Initial price of these systems are down significantly in the past few years with support of government's programs and homeowners tax credits but still have a payback period time of around 14 years. This problem cannot be justified easily in everyday construction practice. Another issue with this system is the large area in the roof they need for solar collectors. Despite all of these issues, implementing a solar water heater will reduce annual energy consumption of DHW more than 90% in the case study project.

Adding costly green technology systems to buildings cannot be justified without any compromise in other areas of design and construction. One of the practical approaches is to implement standard materials and building components instead of custom orders. For instance, builder can order a standard color stone countertop instead of custom color that is in some cases is half the price and carry the same quality as standard color. This strategy can be applied to many decorative items in the building without damaging the quality of project.

In the construction chapter, cost analysis of green package technology indicates the effectiveness of these systems in marketing of the final product. The design decision for the case study project is to install an indirect closed loop passive solar collector with electric backup element. The selected system is capable of providing 80 gallons of hot water with support of backup element and 50 square feet of collector. Figure 6.3, shows the diagram of a closed loop solar water heater.

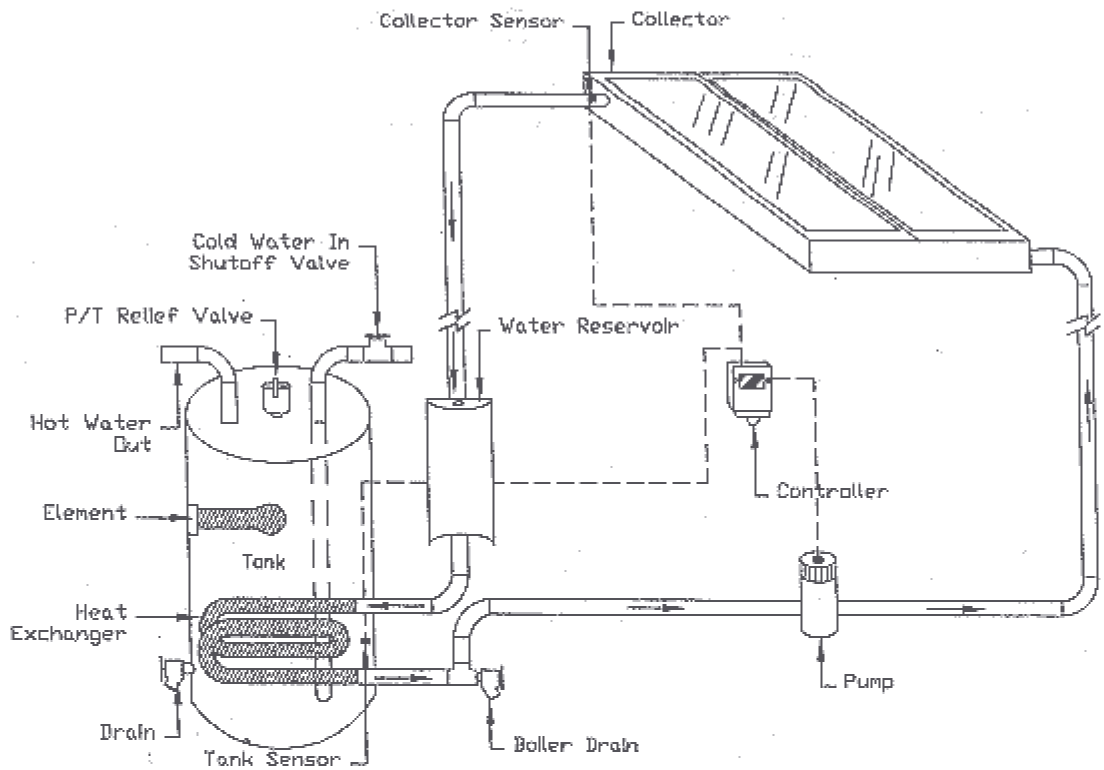


Figure 6.3: Pluming diagram of a solar water heater

Sizing a solar water heater involves determining the total collector area and the storage volume required to provide 100% of household hot water during the summer. Solar storage tanks are usually 50-, 60-, 80-, or 120-gallon capacity. A small (50 to 60 gallon) system is sufficient for 1 to 3 people, a medium (80-gallon) system is adequate for a 3- or 4-person household, and a large (120-gallon) system is appropriate for 4 to 6 people. A rule of thumb for sizing collectors is to allow about 20 square feet of collector area for each of the first two family members and 8 square feet for each additional family member if you live in the Sun Belt. Allow 12 to 14 additional square feet per person if you live in the northern United States. A ratio of at least 1.5 gallons of storage capacity to

1 square foot of collector area prevents the system from overheating when the demand for hot water is low. In very warm, sunny climates, experts suggest that the ratio should be at least 2 gallons of storage to 1 square foot of collector area [23].

On-Site Renewable Energy Production

Finding a suitable energy production system for each project depends on various factors such as:

- Building Type
- Climate zone
- Building Size
- Economics and Costs
- System Sizing
- Codes and regulations
- Installation and maintenance considerations

Evaluations of these factors support the selection of an optimum system. In the climate zone of the case study project, insufficient wind and hydropower energy in the region eliminates wind electric and microhydropower systems from the option list.

A solar radiation map of the project shows an acceptable level of radiation to use photovoltaic systems. Figure 6.4 displays the availability of solar radiation in the United States. Most of the State of Georgia is located in a 5-6 kWh/m2/day zone, which is a reasonable level of radiation to have PV systems.

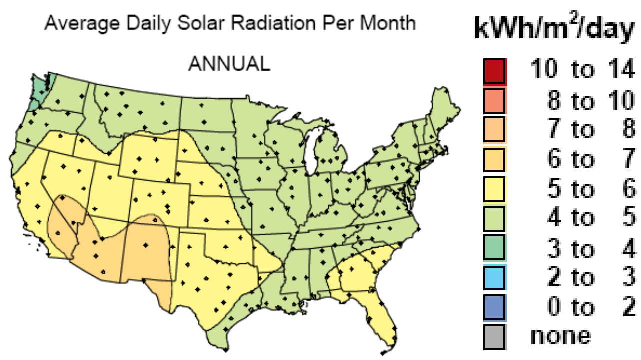


Figure 6.4: Average daily solar radiation map

Selection and Sizing PV Systems

Selection of PV systems depends on various factors such as system efficiency, economics and costs, and durability of systems. There are three basic types of PV panels. Monocrystalline cells are slices from a single crystal of silicon. These are the most efficient and the most expensive to produce. Polycrystalline cells are a slice cut from a block of silicon consisting of a large number of crystals. These cells are slightly less efficient and slightly less expensive than monocrystalline cells and again need to be mounted in a rigid frame. Amorphous cells are manufactured by placing a thin film of amorphous (non crystalline) silicon onto a wide choice of surfaces. These are the least efficient and least expensive to produce of the three types. Any of these panels can be used for a residential project. Availability, costs and efficiency of systems are major factors to select the best system for each project.

In net-zero energy projects, a building's annual energy consumption is the key indicator to estimate the size of PV panels. In order to generate energy equal or greater than annual building energy consumption, available dedicated area to panels (roof), PV panels' efficiency, and orientation of panels are the main factors in calculation of on-site energy production.

To maximize on-site energy production, orientation and tilt angle are the main design factors to be optimized when roof area and the efficiency of panels are fixed parameters. PV modules should be oriented geographically to receive the maximum amount of daily and seasonal solar radiation. In general, the optimum orientation for a PV module in the northern hemisphere is true south. However, your modules can face up to 45º east or west of true south without significantly decreasing its performance [24]. Optimization of the panels' tilt can maximize energy production by up to 33% based on the case study results. Most of the modules can be mounted flat on pitched roofs. It is important for architects to calculate this angle and apply into their design (roof angle). The optimal tilt angle for your modules is an angle equal to your latitude [24]. There are levels of uncertainly embedded with these systems. Radiation intensity in micro scale and material performance degradation are two of these factors.

The case study project is a grid-tied energy-neutral project. Renewable energy systems are capable of powering houses to some acceptable levels of comfort, still with high level of uncertainty in operation and high price of energy storage systems, people prefer advantages that grid-connection offers. For on-site energy production systems, a polycrystalline system with 15% efficiency is an ideal choice to meet construction budget criteria and generate enough electricity based on available roof area to cover the building's annual electricity demand.

The Building Energy Calculator Tool is capable of estimating monthly energy generation based on area, efficiency, type and tilt of panels. The latitude of the city of Atlanta is approximately 33 degrees. The calculator indicates maximum on-site energy production with a 30-degree angle. A 1.75% energy reduction is found at 45 degrees, 8% reduction at 60 degrees and 33% reduction at 90-degrees compare to 30-degree tilted angle. This angle is also the optimal degree angle for water heater solar collectors. The ability of the performance tool to calculate optimal scenario in a few minutes, makes the design process very easy for architects.

In the design of the project, the optimum slope of the roof is 30 degrees to observe maximum solar radiation into PV and Solar collector panels. Figure 6.5 illustrates a section of the project with 30-degree roof angle and orientation of PV panels and solar collectors in south elevation.

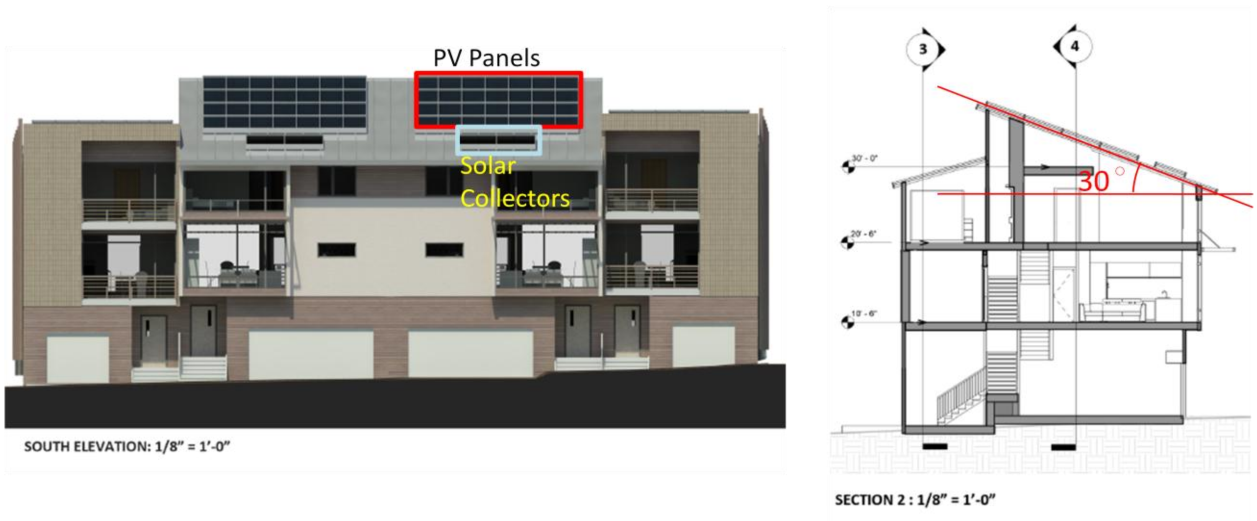


Figure 6.5: South elevation and a building section of the case study project

CHAPTER 7

BUILDING ENERGY CONSUMPTION ANALYSIS

The overall concept of the net-zero design process is to minimize a building's energy demand based on building science and the creativity of architects in combination with architectural design, advanced construction details, and green technologies. With low energy demand, building systems will consume less energy and provide better physical comfort for occupants. In this chapter, results are presented from performance factors analysis of building systems and economics which support the selection of optimum efficiency factors for building systems. Efficiency and price are not corresponding in system selection. In some cases, a 10 % increase in energy efficiency may add up to 50% or even more in system costs. On the other hand, results of on-site energy production set a performance base to support decision making for building systems efficiency.

Analysis of Building Systems Performance Factors

The notion of these analyses is to measure the effectiveness of performance parameter improvements in total building energy consumption. In order to perform this process, we use the case study simulation model with the average performance of generic building systems. During the analyses process, this model is called option 1. Building energy demand is optimized in the option 1 simulation model based on results of energy demand optimization process. Cooling and heating systems consume a big portion of buildings annual energy consumption. Figure 7.1 displays breakdown of building systems energy consumption. 25% is estimated for heating load and 14% for cooling in the case study project total energy consumption.

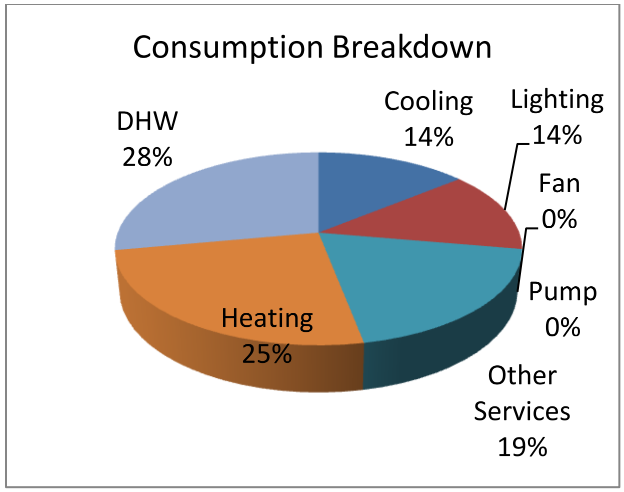


Figure 7.1: The case study energy consumption breakdown

In option one simulation model, HVAC system is selected as a split direct exchange heat pump unit with electric resistance backup system. Average efficiency of heat pump units is 13 SEER for cooling and 7.7 HSPF for heating season.

An ideal HVAC system for this project is the ductless heat pump unit. Because of the technical advantages of this system, its average efficiency is higher than ducted systems. The selected system for this project have an average SEER of 16 for cooling and HSPF of 10 for heating. A unit with this performance has a higher price tag compared to conventional systems but has many advantages such as quietness, no air handling unit, and no leaky ducts. Figure 7.2 shows simulation results of cooling and heating energy consumption of generic and advanced HVAC system for the project. Top diagram is simulation result of generic system and diagram below shows result of ductless system with higher efficiency. A 29% improvement in cooling energy and 26% reduction in heating energy consumption are results of HVAC system improvements.

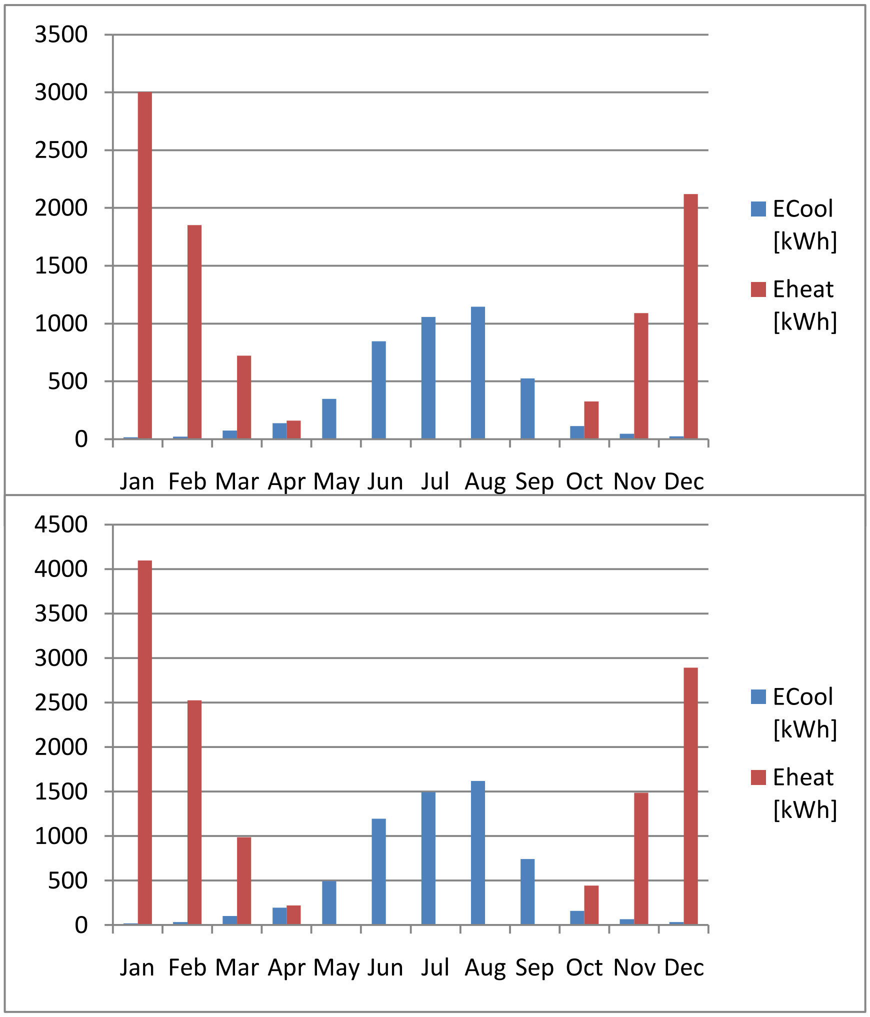


Figure 7.2: Annual conventional HVAC unit energy consumption (Top)
Annual ductless heat pump unit energy consumption (Below)

Simulation results estimate 11% reduction in total building energy consumption by upgrading the HVAC unit of the case study project. Figure 7.3 Illustrates monthly changes in total building energy consumption in both cases.

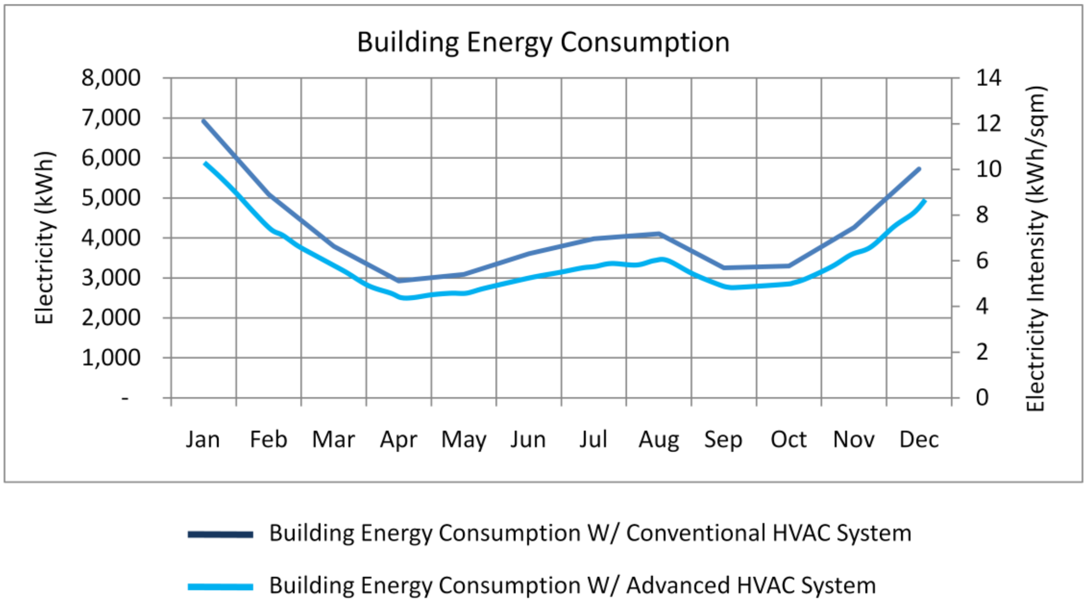


Figure 7.3: Building energy consumption and different HVAC systems

In conventional homes, water heaters are the second biggest energy consumers after heating systems. In the case study project, since energy demand is optimized to the lowest possible level, DHW counts for 28% of annual energy consumption. Upgrading water heater system from electric/gas system to solar water heater can significantly reduce electricity usage. The selected system has a 50 square foot advanced solar collector with an 80 gallon hot water capacity while provides almost all the required hot water for a townhome unit. Simulation results show a 32% reduction in building energy consumption as a result of using this system instead of conventional water heaters. One of the reasons for this significant improvement is the size and efficiency of collectors and the size of water heater tank (80 gallons). Figure 7.4 shows decrease in energy consumption using solar water heater.

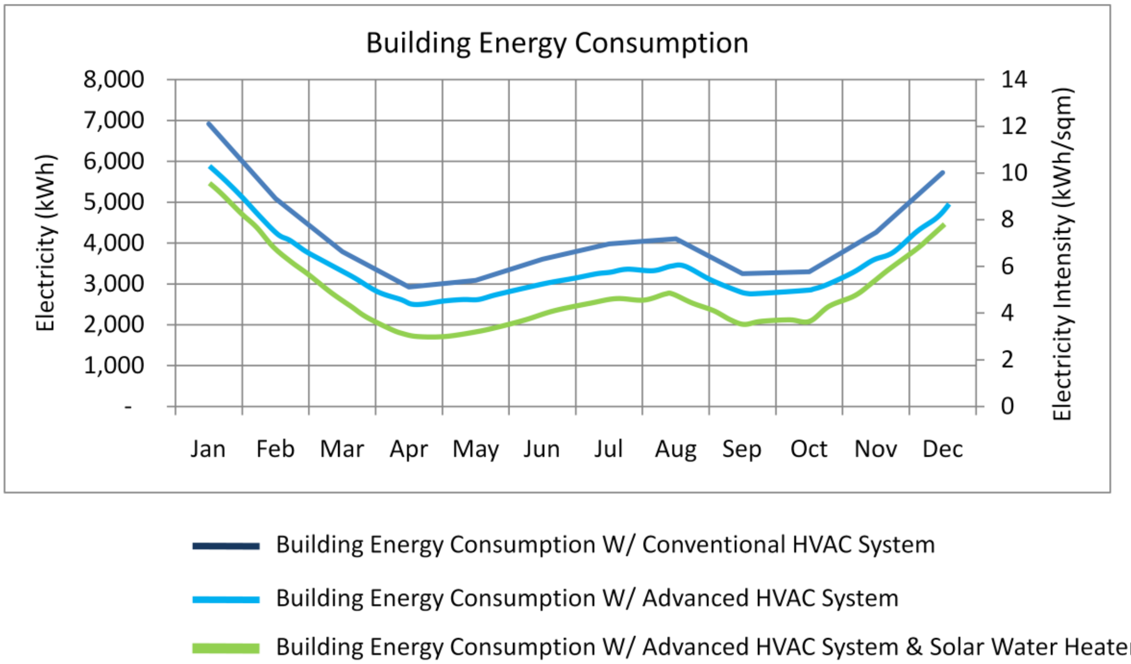


Figure 7.4: Building energy consumption and different mechanical systems

Design Environmental Impacts Assessment

Despite the financial benefits of a net-zero energy home, the energy-neutral initiative emphasizes the environmental benefits of this movement. The Building Energy Performance Tool calculates monthly-generated greenhouse gases of projects, based on the design decisions of architects. In addition, there is a scoring system in this tool that evaluates the environmental impacts of the building in five categories and scores them from a range of -1 (lowest level) to 3 (highest level). The higher score in each category indicates lower impacts on the environment. There are four categories in this system: thermal need, energy delivered, CO2 Generation, and NOx & SOx emissions. In order to score in CO2 and NOx, SOx categories, having an on-site clean energy production system is required.

To demonstrate environmental impacts of a design decision, we have compared improvements on scoring system by using high performance HVAC systems, Solar water heaters and on-site electricity generation by PV systems.

Tables 7.1.1,2,3,4 shows step by step improvements in environmental performance of the case study building.

Table 7.1.1: Energy performance assessment scores with conventional HVAC systems

$Q_{design,nd}$ [kWh/m^2/yr]	**87**	Q_{ref_nd} [kWh/m^2/yr]	151	**EPCnd**	0.57	3

[E.2] Reference Value and EPC calculation

$E_{design,del}$ [kWh/m^2/yr]	**90**	E_{ref_del} [kWh/m^2/yr]	120	**EPCdel**	0.75	1

[E.3] Reference Value and EPC calculation

$E_{design,p}$ [kWh/m^2/yr]	**304**	E_{ref_p} [kWh/m^2/yr]	307	**EPCp**	0.99	0

[E.4] Reference Value and EPC calculation

$CO2_{design}$ [g/m^2/yr]	**66733**	$CO2_{ref}$ [g/m2/yr]	62350	**EPCco2**	1.07	-1

[E.5] Reference Value and EPC calculation

NOx_{design} [g/m^2/yr]	**122**	NOx_{ref} [g/m^2/yr]	110	**EPCnox-sox**	1.2	-1
SOx_{design} [g/m^2/yr]	**349**	SOx_{ref} [g/m^2/yr]	270			

The next table indicates performance improvements by adding a high performance HVAC system.

Table 7.1.2: Energy performance assessment scores with high performance HVAC systems

$Q_{design,nd}$ [kWh/m^2/yr]	**87**	**Q_{ref_nd} [kWh/m^2/yr]**	151	**EPCnd**	0.57	3

[E.2] Reference Value and EPC calculation

$E_{design,del}$ [kWh/m^2/yr]	**80**	**E_{ref_del} [kWh/m^2/yr]**	120	**EPCdel**	0.67	2

[E.3] Reference Value and EPC calculation

$E_{design,p}$ [kWh/m^2/yr]	**273**	**E_{ref_p} [kWh/m^2/yr]**	307	**EPCp**	0.89	0

[E.4] Reference Value and EPC calculation

$CO2_{design}$ [g/m^2/yr]	**59843**	**$CO2_{ref}$ [g/m2/yr]**	62350	**EPCco2**	0.96	0

[E.5] Reference Value and EPC calculation

NOx_{design} [g/m^2/yr]	**109**	**NOx_{ref} [g/m^2/yr]**	110	**EPCnox-sox**	1.08	-1
SOx_{design} [g/m^2/yr]	**313**	**SOx_{ref} [g/m^2/yr]**	270			

The next table shows effects of implementing solar water heaters instead of electric water heaters on performance improvements on scoring system.

Table 7.1.3: Energy performance assessment scores with solar water heater systems

$Q_{design,nd}$ [kWh/m^2/yr]	**87**	**Q_{ref_nd} [kWh/m^2/yr]**	151	**EPCnd**	0.57	3

[E.2] Reference Value and EPC calculation

$E_{design,del}$ [kWh/m^2/yr]	**54**	**E_{ref_del} [kWh/m^2/yr]**	120	**EPCdel**	0.45	3

[E.3] Reference Value and EPC calculation

$E_{design,p}$ [kWh/m^2/yr]	**183**	**E_{ref_p} [kWh/m^2/yr]**	307	**EPCp**	0.6	3

[E.4] Reference Value and EPC calculation

$CO2_{design}$ [g/m^2/yr]	**40203**	**$CO2_{ref}$ [g/m2/yr]**	62350	**EPCco2**	0.64	2

[E.5] Reference Value and EPC calculation

NOx_{design} [g/m^2/yr]	**73**	**NOx_{ref} [g/m^2/yr]**	110	**EPCnox-sox**	0.72	1
SOx_{design} [g/m^2/yr]	**210**	**SOx_{ref} [g/m^2/yr]**	270			

The next table shows positive environmental effects of solar PV system on performance improvements of scoring system.

Table 7.1.4: Energy performance assessment scores with PV systems

$Q_{design,nd}$ [kWh/m²/yr]	**87**	**Q_{ref_nd} [kWh/m²/yr]**	151	**EPCnd**	0.57	3

[E.2] Reference Value and EPC calculation

$E_{design,del}$ [kWh/m²/yr]	**-8**	**E_{ref_del} [kWh/m²/yr]**	120	**EPCdel**	-0.07	3

[E.3] Reference Value and EPC calculation

$E_{design,p}$ [kWh/m²/yr]	**-27**	**E_{ref_p} [kWh/m²/yr]**	307	**EPCp**	-0.09	3

[E.4] Reference Value and EPC calculation

$CO2_{design}$ [g/m²/yr]	**-5938**	**$CO2_{ref}$ [g/m2/yr]**	62350	**EPCco2**	-0.1	3

[E.5] Reference Value and EPC calculation

NOx_{design} [g/m²/yr]	**-11**	**NOx_{ref} [g/m²/yr]**	110	**EPCnox-sox**	-0.11	3
SOx_{design} [g/m²/yr]	**-31**	**SOx_{ref} [g/m²/yr]**	270			

CHAPTER 8

CONSTRUCTION, COSTS, RISK ANALYSIS AND MARKETING

Schematic design starts with guidelines drafted in the architectural program and continues through the design development phase. In this case study, the main focus will be on implementing building science strategies, tools and technologies into building program and design process in an efficient and practical method.

Construction

Homebuilders who want to enter into the net-zero energy market need to be ready to face many changes and challenges in the process of design and construction. There are some barriers in design-build process of NZE homes such as diversity in building codes with local amendments, lack of easy access to information about new products and inadequate training on products, systems and installation. These obstacles generate unwillingness among contractors-influenced by sub-contractors' inability to maintain their standard performances and costs. Attending green building workshops and programs such as Energy Star, LEED for Homes, or other similar short-term trainings would prepare builders mentally and technically to participate in design-build process of net-zero energy homes.

Design-Build

Unlike commercial projects, construction documents of homes do not have a sufficient details and specifications. Therefore, success in such projects depends heavily on general contractor knowledge to control overall quality and cost. Since the proposed methodology in this study is a knowledge-based process, it requires contractors to be involved during the design phase as an active consultant to support cost estimating and verifying durability and effectiveness of specified systems and materials.

A design-build system would be an ideal method for energy-neutral home projects. A professional team with a systematic project delivery system will be able to reduce uncertainties in total project cost, quality and construction schedule of projects and increase probability of achieving net-zero energy goals.

Trade-off Method

Design and construction costs of energy efficient buildings are generally higher than conventional structures. In homes, this increase could be between a range of 10-30% depends on location and design. Some of these up-front investments will be offset during the lifetime of a home by reducing the energy consumption from the grid. This type of payback does not appear promising to all investors and homebuyers. A trade-off methodology can offset some of these initial costs by a good fraction. This method is not backed by any scientific research and it is based on personal experience in design and construction practice. Based on the price range of a house and which category it falls in, the building finish will consume on average between 30-70% of the total construction costs depends on the house price range category. The building finishes includes items like building trims and accessories such as flooring, cabinets and others from the inside of houses and building cladding materials and systems from the outside of buildings.

The trade-off method exchanges some of these materials and details to save money and cover parts of expenses of green technologies. Some of these trade-offs can be done by using standard materials instead of special orders. For instance, using counter tops with standard colors with the same quality can save a few thousand dollars in some projects. Kitchen cabinets with standard cosmetic details and standard colors, interior doorknobs, flooring systems and many more can be carefully selected to save thousands while keeping the same quality. Keep in mind that this method can be effective in mid to high price range homes. In economically constructed homes, there is not enough practical trade-off options available to support green technology's costs.

Quality Assurance

The implementation of a systematic QA into process of net-zero buildings will positively affect overall energy and comfort level of the building performance. A structured system is required to review and inspect the design and the construction process of projects. This system should have testing and be able to facilitate documentation of that testing. Office standards must be formally established so that there is no confusion regarding auditing procedures and methodologies. The Knowledge Base (KB) is a searchable electronic database of all knowledge related to energy engineering. The KB contains the notes from training seminars, energy auditing guides, energy auditing standards, and information on all other topics that engineers may need to access. The primary feature of a KB is to be a single source to answers to most of the questions related to home energy services.

An effective delivery system would be able to check the accuracy of inputs and outputs of a simulation model as well as implementation of these results into construction documents during design period. In the construction phase, a serious standard of testing and routine inspections such as blower door tests, duct leakage testing, and verification of building systems and material installation and optimum performance would increase construction quality and performance of the finished product.

Finance and Payback Period

Life cycle cost analyses of net-zero energy projects in comparison to purely grid based energy projects often favor the net-zero approach due to the substantial savings in energy costs over the life of the facility [25]. Although the low cost of energy from the grid makes net-zero energy concept less attractive, some experts believe if home owners focus more on life cycle savings, net-zero homes will gain in popularity with the support of tax incentives and changes in energy building codes.

Utility rates are on the rise and the price of energy efficient systems are lowering due to more stringent building energy codes, suggesting that in the near future moving toward net-zero will be more economically justifiable.

In the case study project, several payback period analyses were conducted for advanced building systems to support design decision making of an optimum system. On the other hand, payback period analysis alongside with trade-off strategy method would create guidelines to balance the final cost of building. For instance, PV systems have a payback period more than 10 years in average cases. Tax incentives can reduce a fraction of the initial costs and lower the payback period time. Payback period analysis also indicates how much of the initial cost of these systems must be offset by trade-offs strategy method to lower the total cost of construction and keep the building in a marketable zone.

The tables below show that the payback period of the case study's PV system is estimated to be around eighteen years after 30% tax incentive reduction. This would increase construction costs by 5-6% for each townhouse unit in this building. The trade-off strategy could be used to reduce initial costs to lower level which payback period become around ten years.

In the case study, the price of an on-site energy production system is estimated at around $22,000 for each unit. Analysis shows there should be around an $8000 cost reduction through trade-offs in order to reduce the payback time to less than ten years.

Considering the 20 years life time of these systems, 10 years payback period could make a reasonable business case. These analyses must be conducted during the preliminary design process of projects in order to achieve optimum design decision results.

Table 8.1: Payback period analyses of a PV system with 30% tax incentive reduction

PV System Payback Period

YEAR	1	2	3	4	5	6	7	8	9	10
Relevant benefits										
Energy Savings (yearly)	$1,211	$1,272	$1,335	$1,402	$1,472	$1,546	$1,623	$1,704	$1,790	$1,879
Tax Credits	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total benefits	$1,211	$1,272	$1,335	$1,402	$1,472	$1,546	$1,623	$1,704	$1,790	$1,879
Expected Rate of Rise in Energy Costs	5%	(This would be ABOVE the rate of inflation)								
Annual Net Costs for Improvements										
Materials Costs	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Maintenance	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total costs	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Net Income:	$1,211	$1,272	$1,335	$1,402	$1,472	$1,546	$1,623	$1,704	$1,790	$1,879
Initial Cost of Investment	$21,875									
Net Cash Flow	($20,664)	$1,272	$1,335	$1,402	$1,472	$1,546	$1,623	$1,704	$1,790	$1,879
Cumulative Net Cash Flow	($20,664)	($19,392)	($18,057)	($16,654)	($15,182)	($13,636)	($12,013)	($10,309)	($8,519)	($6,640)
Undiscounted payback period:	**17.25 Years**									
Discount Rate	6%	**<< This is the cost of borrowing the money necessary to make the energy efficient improvements**								
Discounted Cash Flow	($19,494)	$1,132	$1,121	$1,111	$1,100	$1,090	$1,080	$1,069	$1,059	$1,049
Cumulative Discounted Cash Flow	($19,494)	($18,362)	($17,241)	($16,130)	($15,030)	($13,940)	($12,861)	($11,791)	($10,732)	($9,683)
Discounted payback period:	**18.22 Years**									

Table 8.2: Payback period analysis of a solar water heater system

Solar Water Heater System Payback Period

Year	1	2	3	4	5	6	7	8	9	10
Relevant benefits										
Energy Savings (yearly)	$366	$384	$404	$424	$445	$467	$490	$515	$541	$568
Tax Credits	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total benefits	$366	$384	$404	$424	$445	$467	$490	$515	$541	$568
Expected Rate of Rise in Energy Costs	5% (This would be ABOVE the rate of inflation)									
Annual Net Costs for Improvements										
Materials Costs	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Maintenance	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total costs	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Net Income:	$366	$384	$404	$424	$445	$467	$490	$515	$541	$568
Initial Cost of Investment	$5,300									
Net Cash Flow	($4,934)	$384	$404	$424	$445	$467	$490	$515	$541	$568
Cumulative Net Cash Flow	($4,934)	($4,550)	($4,146)	($3,722)	($3,278)	($2,810)	($2,320)	($1,805)	($1,264)	($696)
Undiscounted payback period:	**13.84 Years**									
Discount Rate	6% << This is the cost of borrowing the money necessary to make the energy efficient improvements									
Discounted Cash Flow	($4,655)	$342	$339	$336	$332	$329	$326	$323	$320	$317
Cumulative Discounted Cash Flow	($4,655)	($4,313)	($3,974)	($3,638)	($3,306)	($2,977)	($2,650)	($2,327)	($2,007)	($1,690)
Discounted payback period:	**14.61 Years**									

Risk Analysis and Uncertainty

The probability of the occurrence of an unfavorable event is called risk. Uncertainty analysis supports the risk measurement process. Uncertainty is defined as the indefiniteness about the outcome of a situation [26]. There are many reasons which building's performances are varied and do not meet design expectations.

- The operational condition is different with performance testing condition
- Discrepancy between design performance expectations and systems initial design purpose.
- Certain part of a system may not perform as it is designed.
- Discrepancy between occupant's operational behaviors
- Simulation errors
- Variation in weather

- Material and system deteriorations

These possibilities are represented as uncertainties in the mathematical concept of risk analysis, reliability of modeling, and data inputs. Experienced analysts should choose a model of a system before performing risk analysis. There is not a perfect modeling approach that can capture all aspects of a system and predict its full spectrum of behavior during operation [27]. Figure 8.1 illustrates the schematic modeling steps [27]. Choosing the appropriate model with the proper level of accuracy depends on the analyst's knowledge of the system and their experience in the field [27].

It is important to identify levels of risk and performance uncertainties embedded in a project during the design process to be able to make relevant statements about the performance of building and declare possibilities that a building may not achieve, net-zero status some years because of these uncertainties.

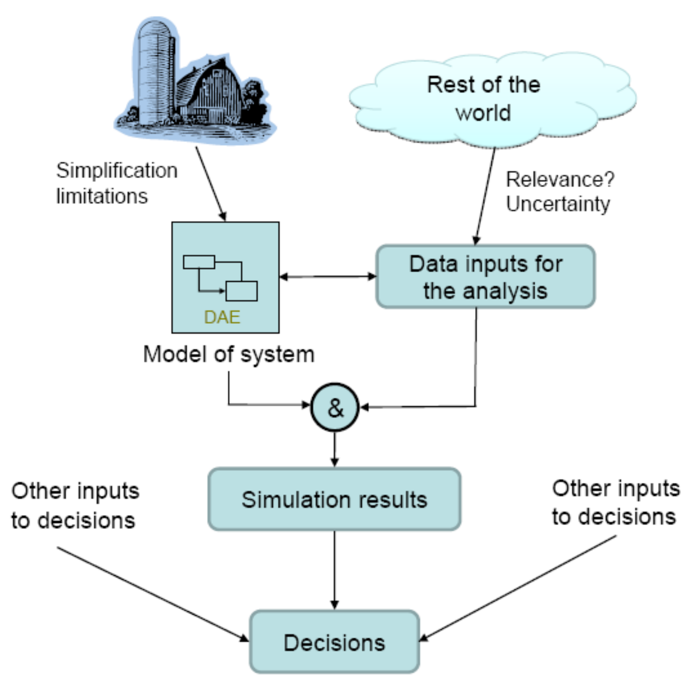


Figure 8.1: Modeling and uncertainties [27]

Uncertainty

In the case study project, in order to make optimum design decisions a comprehensive sensitive parameter analysis evaluates the importance of these factors in building energy demand and delivered energy. Figure 8.2 and 8.3 illustrates the sensitivity of system's parameters in building energy demand and delivered energy as determined by Model Center.

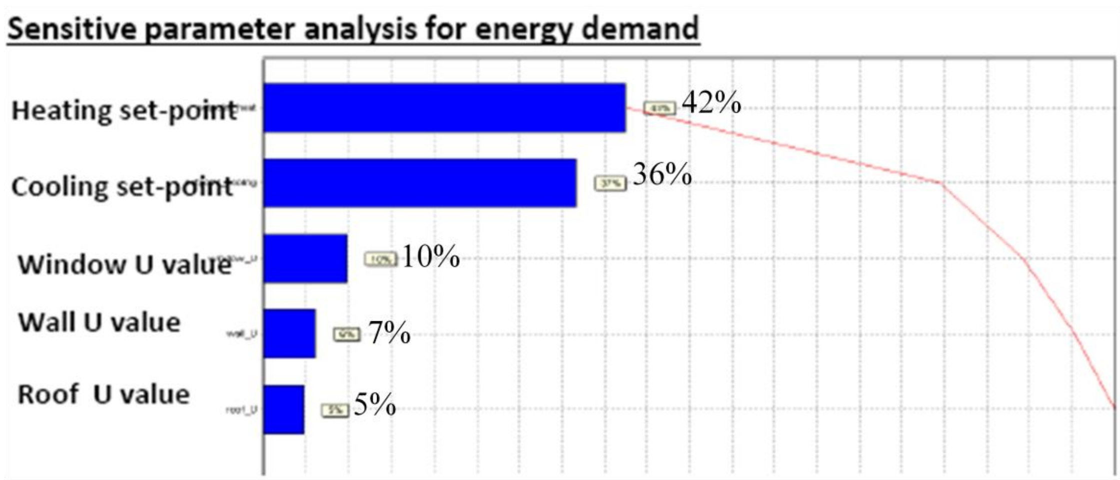


Figure 8.2 Case study sensitive parameter analyses of energy demand

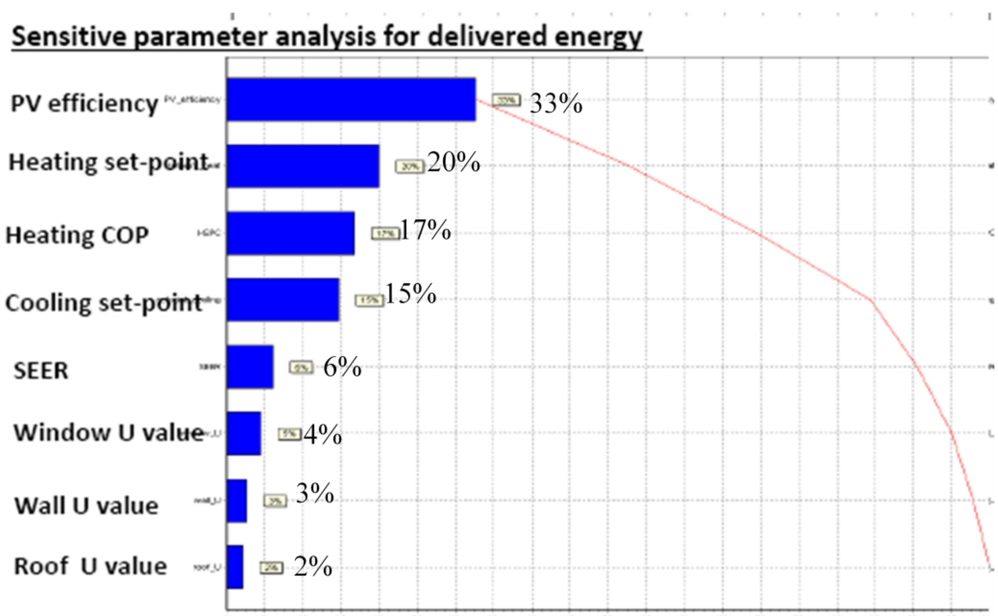
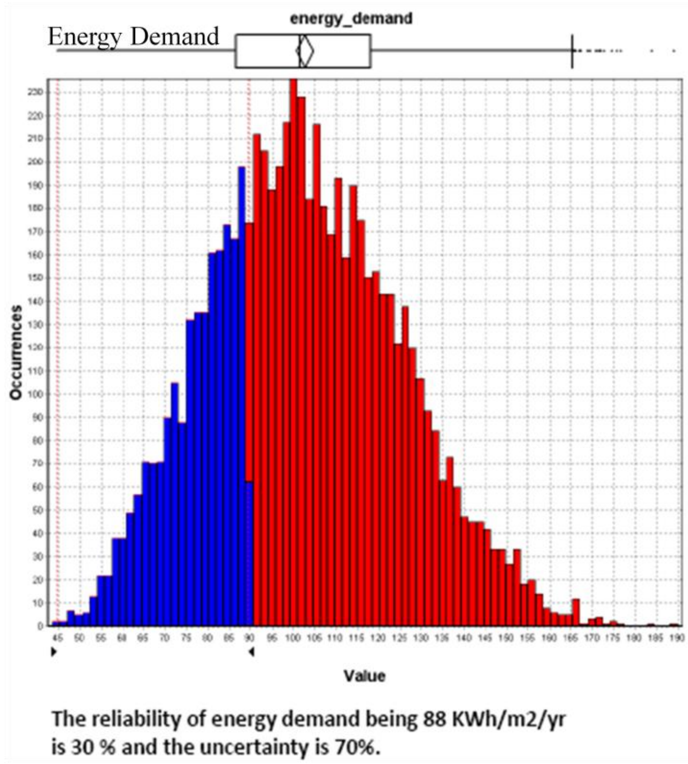


Figure 8.3 Case study sensitive parameter analyses of delivered energy

Results indicate that the heating and cooling set-points are the most sensitive parameters in building energy demand and that the U-value of windows is more sensitive than walls and roof U-value in building energy demand.

Risk

Uncertainty analysis of energy demand and delivered energy can be used as a good indicator to measure reliability of building performances. Risk analysis of the case study indicates that the reliability of the energy demand being at 88 kWh/m2/yr is around 30%, which demonstrates a low reliability to be a net-zero building if the on-site energy production were designed based on this. The probability of building’s energy production to be around 105 kWh/m2/yr will increase reliability of being net-zero more than 50% and energy production of 135 kWh/m2/yr has 90% reliability for the building. Figure 8.4 illustrates uncertainty analysis of energy demand.



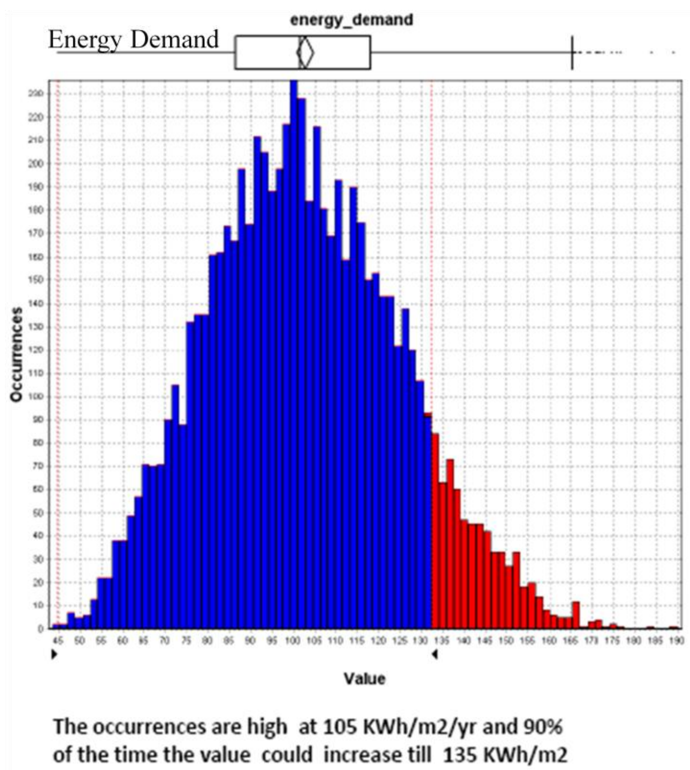


Figure 8.4: Probability analysis of annual energy demand

The importance of probability analyses of energy consumption is to be able to maintain the net-zero energy status. In this case, if on-site energy production systems are designed based on 20 kWh/m2/yr the probability of being net-zero increases above 90%. Overall results of this process can support design decision-makings and reliability of the building as a net-zero energy building.

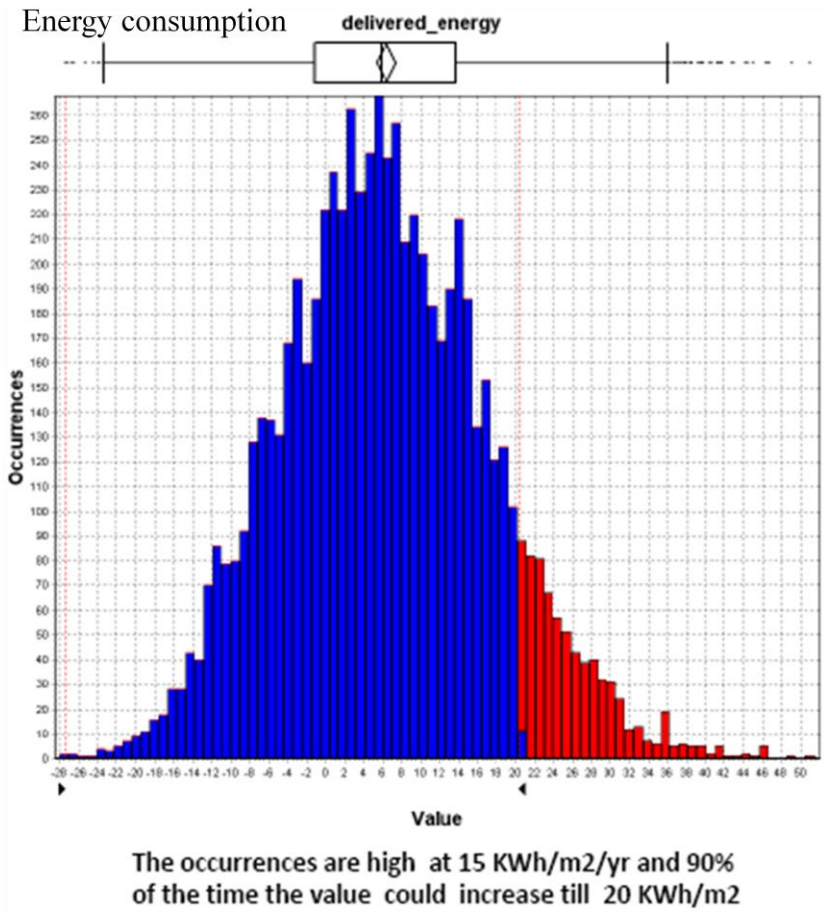


Figure 8.5: Uncertainty analysis of annual energy consumption

Marketing Goals and Strategies

Environmental issues are not in the priority list of investors. Long and short-term profitability are the main driving factors for a sustainable business. In residential market, the implementation of net-zero housing needs to be analyzed separately in different building categories. For instance, single-family homes fall into three categories: economy-level, mid-range and high-end homes. Similar arrangements can be established for multi-family houses such as townhouses and low-rise condominium buildings.

The ultimate goal is to have buildings that are considered upgraded, comfortable, and that save money by on-site energy production while being competitive in the housing market. It is not realistic to believe that businesses will go through relatively complex process of net-zero design just for the sake of environment. This would not be a constructive argument if we believe it is responsibility of individuals to solve environmental concerns and problems. A well designed and constructed net-zero house in the mid-range price will be considered an upgraded home and can be appraised above the average price range in its own category. For instance, if the price range of mid-range single family homes are between $450,000 and $480,000 in a neighborhood, a net-zero home can be easily appraised at around $480,000 plus up to 5% for energy saving features. When it comes to appraising a net-zero home, it will be considered a well-upgraded building compared with conventional houses. This type of evaluation is even more practical for high-end houses in which a 5% price increase can be less effective in the building total cost. The economic houses do not have enough space for trade-off strategies nor for energy saving features. More than 10% price increases in an energy package will significantly effect the marketability of such a project.

This appraisal strategy can be a good guideline for designers and builders to control the total building cost and feasibility study of their projects. Unlike hybrid cars, which can be sold on average 25% above conventional cars in their category, homes cannot be marketed more than 5% above their average competition due to the lower price of energy for homes. In the current market, the building value can be appraised alongside with highest values in their category plus maximum 5% for their overall economical benefits of purchasing (tax incentives), zero energy cost (marginal incomes occasionally) and low operational costs of them.

In the case study building, market studies show a range of $290,000- $320,000 for newly built two bedroom townhomes and up to $350,000 for three bedroom units in the neighborhood. Figures 8.6 illustrates two exterior views of the case study project and figure 8.7 show some pictures of assessed homes in the same area.

Figure 8.6: South and North views of the case study building

2 Bedroom Townhome
Appraised at $298,000.00

3 Bedroom Townhome
Appraised at $337,000.00

Figure 8.7: South and North views of the case study building

The case study is a quadplex building with 2, two-bedroom and 2, three-bedroom units. Detailed cost estimate shows the total cost of each two-bedroom unit to be around $354,000 and $380,000 for the three- bedroom units. The three- bedroom unit’s costs are 8.6% above the market price while the two bedrooms are standing around 10.6% above the market value. Despite this, given that most newly constructed net-zero homes cost way above average homes, an average cost of 10% above the value of conventional buildings could be a good sign for a marketable product. The methodology demonstrated through design process of the project indicates relatively good achievements in cost-control and performance reliability in design process of net-zero projects.

CHAPTER 9

CONCLUSION

The net-zero (near zero) homes are immerging slowly from an experimental idea into a mainstream building industry. Current worldwide energy and environmental crises are the main contributors to this process. This study is aimed to achieve a comprehensive yet simplified methodology to build marketable net-zero houses which can be designed with the same budget as conventional buildings. In this study, barriers are identified during the design process with proposed solutions and strategies to overcome or reduce their impacts on the results. The main obstacle, which is connected to every stage of design and construction, is the final cost. A case study design project is re-examined to layout a systematic design process for a low-rise net-zero energy townhouse project with available technology and a specified budget. The result is expected to be a marketable product. The target is pursued with a front-loaded design process and an analytical trade-off strategy. Having a designer with strong knowledge of building science, architectural design, and construction management is a prerequisite to success. A user-friendly simulation tool which exclusively supports energy-neutral residential buildings is another key to reducing the time and cost of design. During the design process, reducing building energy demand in a steady-state condition without HVAC systems is the main key factor to achieve an ideal design to reduce the total building energy consumption. Analytical analysis during selection of building materials and systems will increase reliability of the systems selections and the design process. The trade-off strategy is applied throughout the design process to implement applicable green products and advanced technologies with some generic and standard building finishes without reducing quality and performance of the buildings.

Re-examination of the results of the case study quadplex project indicates that reducing energy demand while implementing solar passive strategies, a tight envelope, an optimum design of glazing systems, an overhangs, and high value insulation materials would effectively reduce building energy consumption. An analytical trade-off strategy can be an effective balancing budget tool to achieve marketability in this type of building. However, during this process results indicate that residential buildings should be categories based on their cost into three levels: economic-level, mid-range and high-end homes.

Economic-level buildings do not offer enough room for the trade-offs. Consequently, the final product's cost is more than 20% of a conventional project, making this category unavailable to creating a marketable product. These price-range buildings still can be designed to be low-energy homes or can still achieve net-zero status if they can purchase renewable energy from the grid.

The case study project falls into the mid-range building category. Marketing analysis shows that a 5% price increase for the net-zero homes compared to conventional homes can result in a marketable and reliable product in the residential market if the net-zero buildings can be considered high technology buildings. Re-examination of the cost estimation of the project shows that the costs of these units on average of 8% above the market value of new homes in their area. The results also show that even though the proposed methodology can significantly reduce the costs and technical difficulties of the design-built process of net-zero homes, the marketability of these buildings still remains as a challenge. New building codes and standards to support advanced design methods, materials, and technologies, as well as tax incentives for designers, builders and homeowners can ease this process.

REFERENCES

[1] National Science and Technology Council Committee on Technology, Federal RDA Agenda for NetZero Energy High Performance Green Buildings, p. 13, 2008.

[2] POGHARIAN, S., AYOUB, J., CANDANEDO, J., ATHIENITIS, A., Getting to A Net Zero Energy Lifestyle in Canada: The Alstonvale Net Zero Energy House Presented to the 23rd European PV Solar Energy Conference, Valencia, Spain, Sept., 2008.

[3] http://greensource.construction.com/news/2010/101122Net-Zero.asp

[4] P. Torcellini, S. Pless, and M. Deru, Zero Energy Buildings: A Critical Look at the Definition, presented at ACEEE Summer Study, 2006

[5] www.floridaenergy.ufl.edu/wp.../FESC-zero-energy-home_final-2.pdf (Accessed April 30, 2011)

[6] www.eceee.org/buildings/MazeGuide2-NetzeroEnergyBldgs.pdf (Accessed April 29, 2011)

[7] Christensen, c., Anderson, R., Horowitz, s., Courtney, A., Spencer, j., BEopt™ Software for Building Energy Optimization: Features and Capabilities, August 2006 • NREL/TP-550-39929

[8] ANDERSON, B. and RIORDEN, M. The Solar Home Book, pp. 19, 1976.

[9] http://passipedia.passiv.de/passipedia_en/basics/the_passive_house_-_historical_review (Accessed April 30, 2011)

[10] http://www.lowimpactliving.com/blog/2009/08/24/net-zero-home-in-chicago-boasts-graywater-system/ (Accessed April 30, 2011)

[11] National Science and Technology Council Committee on Technology, Federal RDA Agenda for NetZero Energy High Performance Green Buildings, p. 23, 2008.

[12] AKBARI, H., Environmental Pollution 116-2002 s119-s126, Presented at the AIAA Shear Flow Control Conference, Snowmass, CO, 1997.

[13] http://www.clarkart.edu/exhibitions/ando/ando.html (Accessed March 30,2011).

[14] STEIN, B. and REYNOLDS, J., S. and GRONDZIK, W., T. and KWOK, A., G. MECHANICAL and ELECTRICAL EQUIPMENT for BUILDINGS, tenth edition, pp. 582, 2006.

[15] ISO/TC 163.(2008). ISO 13790:2008 Energy performance of buildings - Calculation of energy use for space heating and cooling.

[16] (Netherlands Standardization Institute, 1999)

[17] Augenbroe, G., & Park, C. S. (2005).Quantification methods of technical building performance. Building Research & Information, 33(2), 159-172.

[18]http://www.energysavers.gov/your_home/insulation_airsealing/index.cfm/mytopic=11600 (Accessed April 19,2011)

[19]http://www.energysavers.gov/your_home/insulation_airsealing/index.cfm/mytopic=11310 (Accessed April 19, 2011)

[20] panasonicvu.buildingmedia.com/.../WhisperComFV-04VE1_Spec.pdf (Accessed April 21, 2011)

[21] http://www.mnshi.umn.edu/kb/scale/hrverv.html (Accessed April 21, 2011)

[22] http://www.energysavers.gov/your_home/water_heating/index.cfm/mytopic=12820 (Accessed April 22, 2011)

[23] http://www.altestore.com/store/Kits-Package-Deals/Climate-freezes-Closed-Loop-Systems/Closed-Loop-Systems-for-1-4-People/Closed-Loop-AC-Drainback/Drainback-w-80-Gal-Tank-52-SqFt-Collectors/p7982/ (Accessed April 22, 2011)

[24] http://www.energysavers.gov/your_home/electricity/index.cfm/mytopic=10830

[25] P. Torcellini, S. Pless, Building Design + Construction: Zero and Net-Zero Energy Buildings + Homes, March, 2011 p.WP15

[26] Garvey, P., Analytical methods for risk management : a systems engineering perspective. 2009, Boca Raton: CRC Press. 264.

[27] HU, H. Risk-Conscious Design of Off-grid Solar Energy Houses, Georgia Institute of Technology, pp. 26, 2009.